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Full Length Research

Environmental Impact Assessment on The Effect of Magnetic Field Strength and Induced Potential on Pacemaker of The Heart, Creek Town, Nigeria

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A research to assess the effect of magnetic field strength and induced potential on patients with pacemaker in Creek Town was conducted. Proton precession magnetometer was used to measure the field strength along vertical and rectangular paths. Readings were taken at the base station and marked locations without much variation, as such there was no need for diurnal correction or presence of anomaly. The strength of the fields due to home appliances were considered as investigated by other researchers to enable us obtain the total possible magnetic field strength (about 0.04 mT). The average magnetic field strength obtained is (3.99093 ± 0.00512) x 10^{-5}T. This result is much lower than the standards which could cause malfunctioning of the device and therefore, suggest a safe environment for all and enhances the computation of potential values. The average potential obtained for three different age groups for men and women are (8.671 ± 0.549) x 10^{-7}V and (7.977 ± 0.505) x 10^{-7}V (greater than 60 years), (8.250 ± 0.523) x 10^{-7}V and (7.606 ± 0.482) x 10^{-7}V (40 – 60 years), (7.630 ± 0.483) x 10^{-7}V and (7.606 ± 0.482) x 10^{-7}V (20 – 40 years) respectively. The probability value is very much lower than 0.01 (about zero) which is intended with the coefficient of determination and correlation coefficient of one.

KEYWORDS: Magnetic field, Potential, Pacemaker, Diameter, Velocity.

INTRODUCTION

The Earth's magnetic field influences the geomagnetic orientation and navigation of some migratory species of salmons, sharks, bird species and honey bees (Johnsen and Lohmann 2005; Kirschvink et al., 2010; Lambinet et al., 2017). The effect of the interaction of magnetic fields with the cardiovascular system is the change in electrocardiograms (ECG). Moving ionic charge carriers (electrolytes) in the blood, when exposed to a magnetic field are subjected to the Lorentz force $\vec{F} = q(\vec{v_b} \times \vec{B})$ that induces an electric potential ∅ ($\emptyset = v_b B d \sin\theta$); v_b is the velocity, d is the diameter of the artery and θ is the angle between the direction of the blood flow and the magnetic field (B). These induced electric potentials have been observed by ECG on mammalians exposed to magnetic field (Kangarlu and Robitaille, 2000).

Safety measures are taken to avoid a potential shift of metal implants and prosthesis that may be influenced by significant torques in strong magnetic field gradients. Time-varying magnetic fields induce electric currents in living systems which could be determined by the Faraday's law of electromagnetic induction. It induces remarkable currents at the macroscopic level but little amount are measured at the cellular level. These currents are generally less than the ones naturally produced by the brain, nerves and heart (Zannella, 1998).

Low magnetic field strength may be safe from the biological recommendation but dangerous for people with pacemaker devices. Most pacemakers implanted of recent are synchronous (that is, they have the ability to perform their function in the presence and absence of magnetic field at the same time). They can be put off when the field influence is massive and are enabled when the heart rate drops below a critical level. Zannella (1998) noted that some pacemakers in the presence of static fields above 0.5 – 1.5mT may reverse into fixed-rate mode (Asynchronous mode). This condition is potentially hazardous and may lead to irregular heart rate that causes poor blood flow (Zannella, 1998). More so, time-varying magnetic fields exceeding the range of 0.1 to 0.4 mT may cause the device to malfunction as the voltage induced depends on the magnetic field. Magnetic field decreases as one move away from the source. Patients with pacemakers are advised to monitor their heart rate at a particular location so as to move away from high field locations if experienced. This is the best way to protect this device. However, warning signs for people with metal implants and prosthesis must be displayed in open places where magnetic fields are above 0.5mT (Zannella, 1998). Local field strength greater than 10G (1T = 10000 Gauss) is sufficient to prompt Electromagnetic Interference (EMI) (Beinart and Nazarian, 2013).

A pacemaker is an electrically charged medical device that drives small electrical impulses to the heart muscle implanted by a surgeon in the skin to manage irregular heartbeats (arrhythmias) so as to pump blood more efficiently to the body. Therefore, pacemaker is needed if the heart is pumping excessively or slowly. In each situation, the body does not get sufficient blood which may cause fatigue, fainting or light headedness, shortness of breath, damage to vital organs and eventual death. With each heartbeat, an electrical impulse travel from the top of the heart to the lower part, leading to the contraction of the heart muscles. A pacemaker has two sections: pulse generator (a metal vessel that contains a battery and the electrical circuitry (motherboard), controls the rate of electrical pulses sent to the heart) and leads or electrodes (are flexible, insulated wires employed in heart chambers and transport the electrical pulses to correct the heart rate). Human exposure to external 50/60-Hz electric and magnetic fields induces electric fields within the body. These induced fields can cause interference with implanted pacemakers. In the case of exposure to magnetic fields, the pacemaker leads are subjected to induced electromotive forces (Trevor et al., 2002). Trigano et al., (2005) recorded a switch to asynchronous mode in three patients with devices set in the unipolar sensing pattern and concluded that many forms of electromagnetic energy may obstruct the functions of implanted pacemakers. This observation was also noticed by Souques et al., (2020). Beinart and Nazarian (2013) mentioned that magnets are useful to all patients with cardiovascular implantable electronic device who are undergoing a procedure that may involve electromagnetic interference.

THEORETICAL BASIS

Magnetic instruments include torsion magnetometers which were later replaced with fluxgate, protein precession and alkali vapour magnetometers (Milsom, 2003). The two main types of resonance magnetometer are the proton free-precession magnetometer [which is the best] and the alkali vapour magnetometer. Both monitor the precession of atomic particles in an ambient magnetic field to provide an absolute measure of the total magnetic field. The proton magnetometer has a sensor which consists of a bottle containing a proton-rich liquid usually water or kerosene, around which coil is wrapped, connected to the measuring apparatus. If two magnetic poles of strength m_1 and m_2 are separated by a distance (r), a force (F) exists between them. If the poles are of the same polarity, the force will push the poles apart and if they are of opposite polarity, the force is attractive and will draw the poles together. This is expressed as:

$$F = \frac{m_1 m_2}{4\pi\mu^2} \quad \ldots(1)$$

μ is the magnetic permeability of the medium separating the poles; m_1 and m_2 are pole strengths and r is the distance between them.

Under equilibrium condition where Hall Effect is

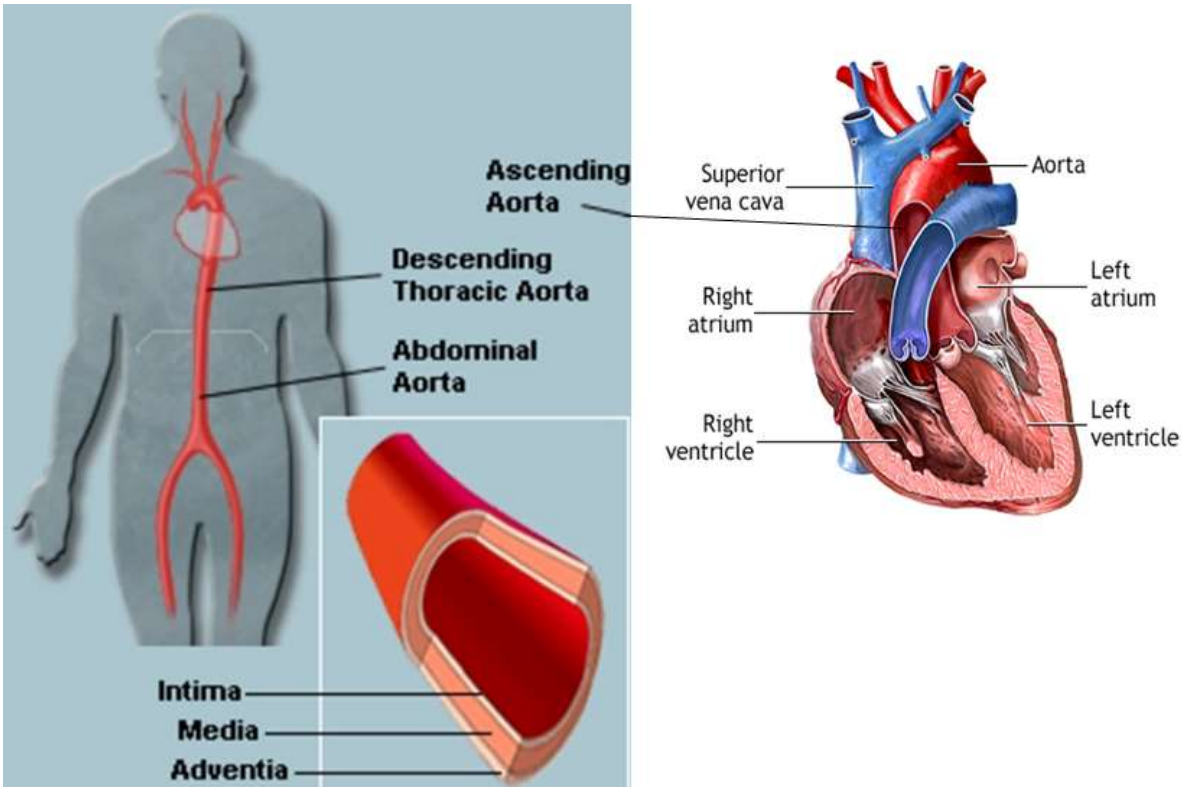

Figure 1. The Human Heart and Picture of Aortic Region (Hoffman, 2013). (https://www.webmd.com/heart/picture-of-the-aorta#1).

established, the electrostatic force $F = qE$ equals the magnetic force $F = qv_bB$ that induces an electric potential when the moving ionic charge carriers (electrolytes) in the blood are exposed to a magnetic field. Considering the basis of Hall Effect,

$$dqE = dqvB; Ed = vBd \quad ...(2)$$
$$\emptyset = Ed \quad ...(3)$$
$$\emptyset = v_bBd \sin\theta \quad ...(4)$$
$$\emptyset = v_bBd \text{ (for } \theta = 90^0) \quad ...(5)$$

Where v_b is the velocity of the human blood, d is the diameter of the artery (aorta), ∅ is the potential and θ is the angle between the direction of the blood flow and the magnetic field.

The heart is a pump which beats frequently about 60 to 100 times per minute. Each heartbeat enables the heart to send blood to different parts of our body such that oxygen is carried to all cells. After supplying the oxygen, the blood proceeds back to the heart. The heart directs the blood to the lungs for enough oxygen. This rotation continues over again. Arteries move blood away from the heart; veins bring blood back to the heart. The heart pumps blood via the arteries (pulmonary) and veins (pulmonary) known as the cardiovascular system. When the aorta contracts, results in our blood pressure (Figure 1) (Hoffman, 2013).

Aorta is the major and largest artery in the human body, starting from the left ventricle of the heart; it extends down the abdomen thus channels the blood pumped, from the heart through the aortic valve. According to Guthmann (2013) it has sections: the ascending aorta (beginning at the upper part of the left ventricle; about 2 inches long (White et al., 2021), the aortic arch (which curves above the heart, to enable branches that transport blood to the head, neck and arms), the descending aorta [includes thoracic aorta which travels down from the arch or through the chest and the small branches supply blood to the ribs and ends in the diaphragm and also includes the abdominal aorta which continues from the diaphragm, splitting to have the paired iliac arteries in the lower abdomen. In order to consider the normal size of the aortic diameter(s) where blood is pumped from the heart to other parts of the body,

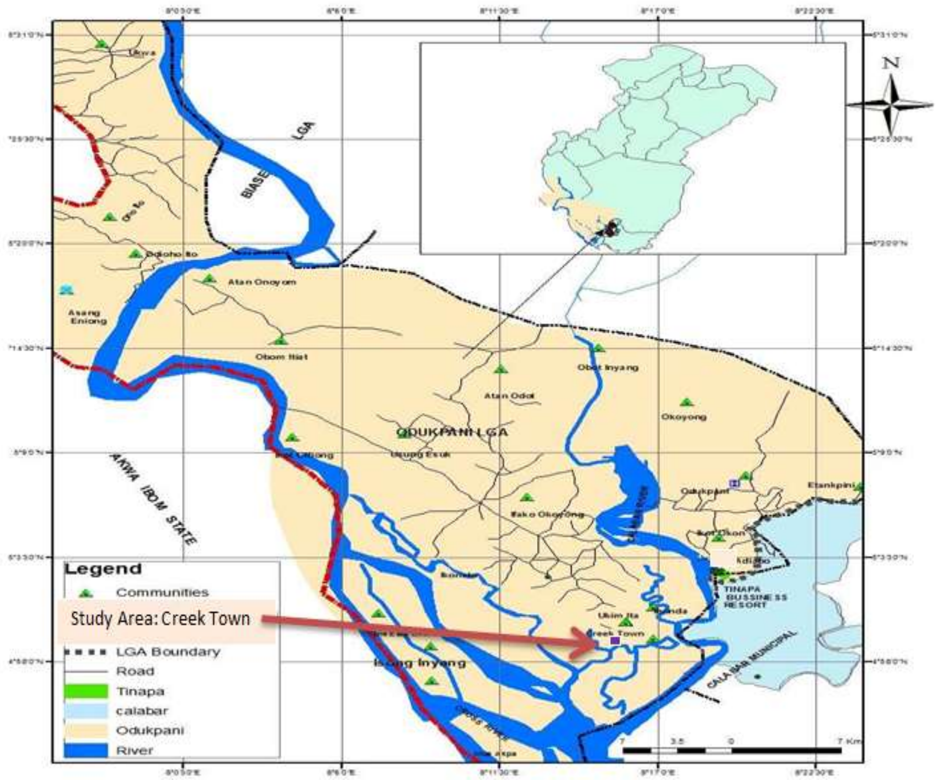

Figure 2. Location Map of Creek Town (Andem, 2012).

we look at recommendations of scientists such as Klarhofer et al., (2001); Erbel and Eggebrecht (2006); Wolak et al., (2008); Wanhainen et al., (2008) and Mao et al., (2008) who have worked on the diameters of aorta as is affected by age and sex and the velocity of blood flow in the human body. The risk of complication in the ascending aorta quickens beyond a diameter of 6 cm (and 7 cm if considered the descending aorta). The major risk cause is smoking. Gabe et al., (1969) examined 23 patients and obtained average peak and mean blood velocities as 66 and 11 cm/sec in the ascending aorta. The velocity arrangement in the ascending aorta was analogous to that achieved by other approaches.

MATERIALS AND METHODS

Location and Geology of The Study Area

Cross River State lies within the range of latitudes $5^0 32^1$ and $4^0 27^1$ North and longitudes $7^0 50^1$ and $9^0 28^1$ East, bounded in the North by Benue state, in the south-west by Akwa Ibom state, in the west by Ebonyi and Abia states. The state shares an internal frontier to the East with the United Republic of Cameroon and its Atlantic coastline is to the south where the Calabar River meets the sea (Atat and Ekpo, 2018). Odukpani is viewed within latitudes 5.0833^0N and 5.1667^0N and longitudes 8.2667^0E and 8.0350^0E, covering an area of roughly 85 square kilometers. As indicated, Creek Town is one of the villages in this area (Figure 2).

Magnetic Surveying (Study Design)

Magnetic data can be acquired in two configurations: (i) a rectangular grid pattern and (ii) a long transverse. Grid data consists of readings taken at the nodes of a rectangular grid; transverse data is acquired at fixed intervals along a line. In both transverse and grid configurations, the station spacing or distance between magnetic readings is important. Local variations or anomalies in the Earth's magnetic field are the result of disturbances caused mostly by variations in concentrations of ferromagnetic material in the vicinity of the magnetometer's sensor. This research was conducted using both configurations. The data depends on the site conditions, size, orientation of the target and financial resources.

A local base station away from the suspected magnetic targets or noise, where the local field gradient is relatively flat was established. The base station was placed at 100m from any large metal objects. To make accurate anomaly maps, temporal changes in the Earth's field during the period of the survey must be considered. Normal changes during the day called diurnal drift are a few tens of nT but changes of hundreds or thousands of nT may occur over a few hours during magnetic storms. The correction for diurnal drift can be made by repeating measurements of a base station at frequent intervals. The measurements at the field stations are then corrected for temporal variations by assuming a linear change of the field by repeating base station readings. Continuously recording magnetometers can also be used at fixed base sites to monitor the temporal changes. If time is accurately recorded at both the base site and the field location, the field data can be corrected by subtraction of the variations at the base site (Rivas, 2009). Since there was no significant variation in the measured parameter, this correction was not necessary. Readings were taken about 5-minute intervals. The distance from the source of the field due to appliances considered was 1m. This resulted in the average minimum and average maximum values of the field.

Magnetic method is used in Engineering for near-surface metal detection. Magnetometer survey provides information on where utilities and other buried materials are located (www.aoageophysics.com). Magnetic exploration referred to "potential fixed field" exploration is used to give geoscientists an indirect way to see beneath the Earth's surface by sensing physical properties of rocks. When a ferrous material is placed within the Earth's magnetic field, it develops an induced magnetic field which is superimposed on the Earth's field at that location creating a magnetic anomaly. Detection depends on the amount of magnetic material present and its distance from the sensor. The anomalies are typically presented on colour contour maps. Common uses of magnetometers include: locating buried tanks and drums, fault studies, mineral exploration, geothermal exploration, mapping buried utilities, pipelines, buried foundations, and also in geothermal activity, the tectonic and stratigraphy of the area by means of the anomalies interpretation of the underground rocks magnetic properties (Rivas, 2009).

STUDY PROCEDURE

The area was cleared and ensured it is free from iron materials which could induce noise. The size of the site was measured and marked out using measuring tape. The field readings at the base station and other points were measured using protein precession magnetometer after every 5 minutes. Stop watch was used to measure the time interval. Global Positioning System was used to read off latitude and longitude values. Ranging poles aid the proper sighting of the base station, sub-station and ensure accurate linear path. All magnetic field strength readings were measured in Gamma but recorded in nanoTesla (nT) such that 1G = 10^{-9}T. Microsoft excel was used to computed calculated parameters, plotting of graphs and regression analysis to obtain the Equations. Surfer 10 was used for the contouring.

ETHICAL CONSIDERATION

The area has meta-sediment and igneous rock that are capable of emitting magnetic radiation which could influence the Earth's magnetic field. The magnetic anomalies can originate from a series of changes in lithology, variations in the magnetized bodies thickness, faulting pleats and topographical relief.

Static and time-varying magnetic fields originating from man-made sources generally have much higher intensities than the naturally occurring fields. This statement is particularly true for sources operating at the power frequencies of 50 to 60 Hz (example, home appliances) which may have the same strength (Mansfield and Morris, 1982), where fields occur that are many orders of magnitude greater than the natural fields at the same frequencies. Other man-made sources are to be found in research, industrial and medical procedures and transportation that are in the developmental stage. Gauger (1984) findings on some electrical appliances with their typical magnetic fields range at a distance of 1m as Can openers (0.07 – 1), Hair dryers (0.01 – 0.3), Electric shavers (0.01 – 0.3), Vacuum cleaners (0.13 – 2), Mixers (0.02 – 0.25), Fluorescent desk lamps (0.02 –

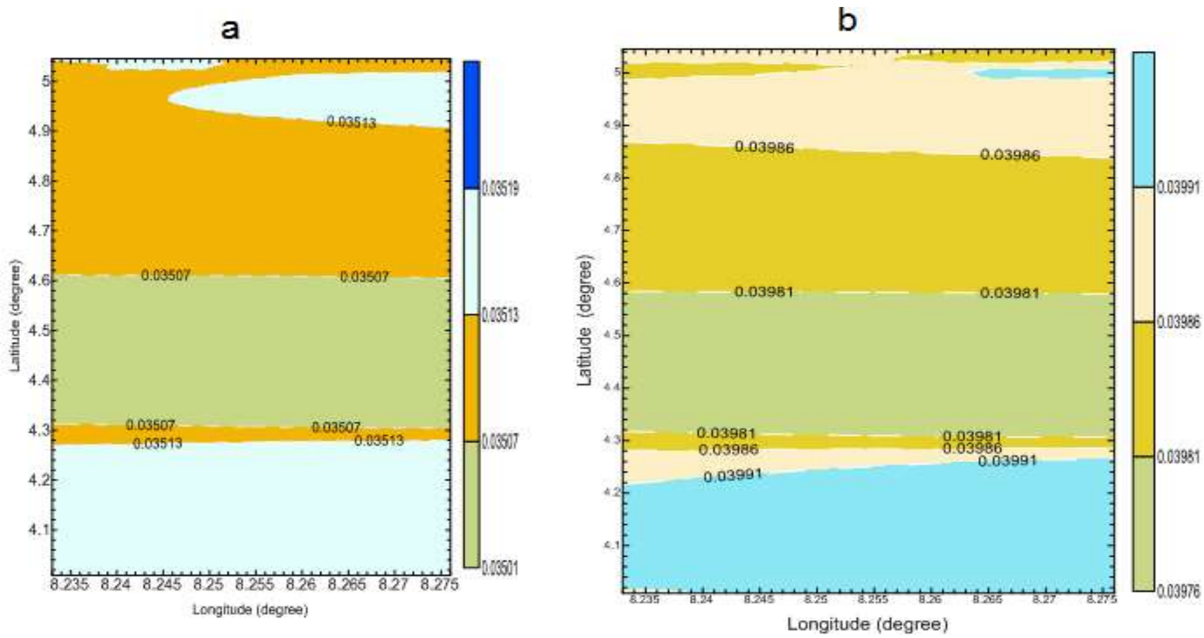

Figure 3. Summarized Information on Total (a) Minimum (b) Maximum B in mT.

0.25), Microwave ovens (0.25 – 0.6), Portable heaters (0.01 – 0.25), Blenders (0.03 – 0.12), Television (0.01 – 0.15), Electric ovens (0.01 – 0.04), Clothes washers (0.01 – 0.15), Irons (0.01 – 0.025), Fans and blowers (0.01 – 0.35), Coffee makers (less than 0.01), Toasters (less than 0.01), Clothes dryers (0.02 – 0.06), Refrigerators (less than 0.01) in microTesla (μT).

RESULT

We conducted research in Creek Town, Cross Rivers State, Nigeria using proton magnetometer to obtain the background information on the strength of magnetic field in the study area to enable us achieve the aim of this research, which is to assess the effect of magnetic field strength and induced potential on patients with pacemaker in Creek Town. This result is presented in Figures 3 to 5. Figure 3 presents the results of measured parameters (magnetic field strength and locations) with the influence of the field due to electrical appliances. The computed or calculated parameter (the induced potential) is presented graphically in Figures 4 and 5. These Figures also present the results of the regression analysis highlighting the coefficient of determination, correlation coefficient and the relationship between magnetic field and the induced potential.

DISCUSSION

We obtained the magnetic field strength as seen in Figure 3 along a vertical traverse (road) and rectangular traverse (pitch) resulting in total magnetic field due to the background and possible home appliances with respect to a distance of 1m away from the devices considered. This process results in two ranges of field values: minimum and maximum. The possible home appliances considered include can opener, electric shaver, vacuum cleaner, fluorescent desk lamp, garbage disposal, microwave oven, portable heater, blender, television, clothes washer, electric iron, fan/blower, coffee maker, toaster, clothes dryer, refrigerator, laptop, video/decoder, printer, radio and phone. The total minimum and maximum magnetic field strength of these appliances are 2.16 mT and 6.905 mT. These values along with the background values constitute the total possible magnetic field likely present in the area of study.

A patient with pacemaker of the heart relies on this device to be able to pump blood from the heart to other parts of the body. If this device is exposed to high static field strength of about greater than 0.5 – 1.5 mT, may reverse from synchronous mode to asynchronous mode making it impossible for continuous pumping of blood from the ailing patient. Similarly, for time-varying magnetic field of greater

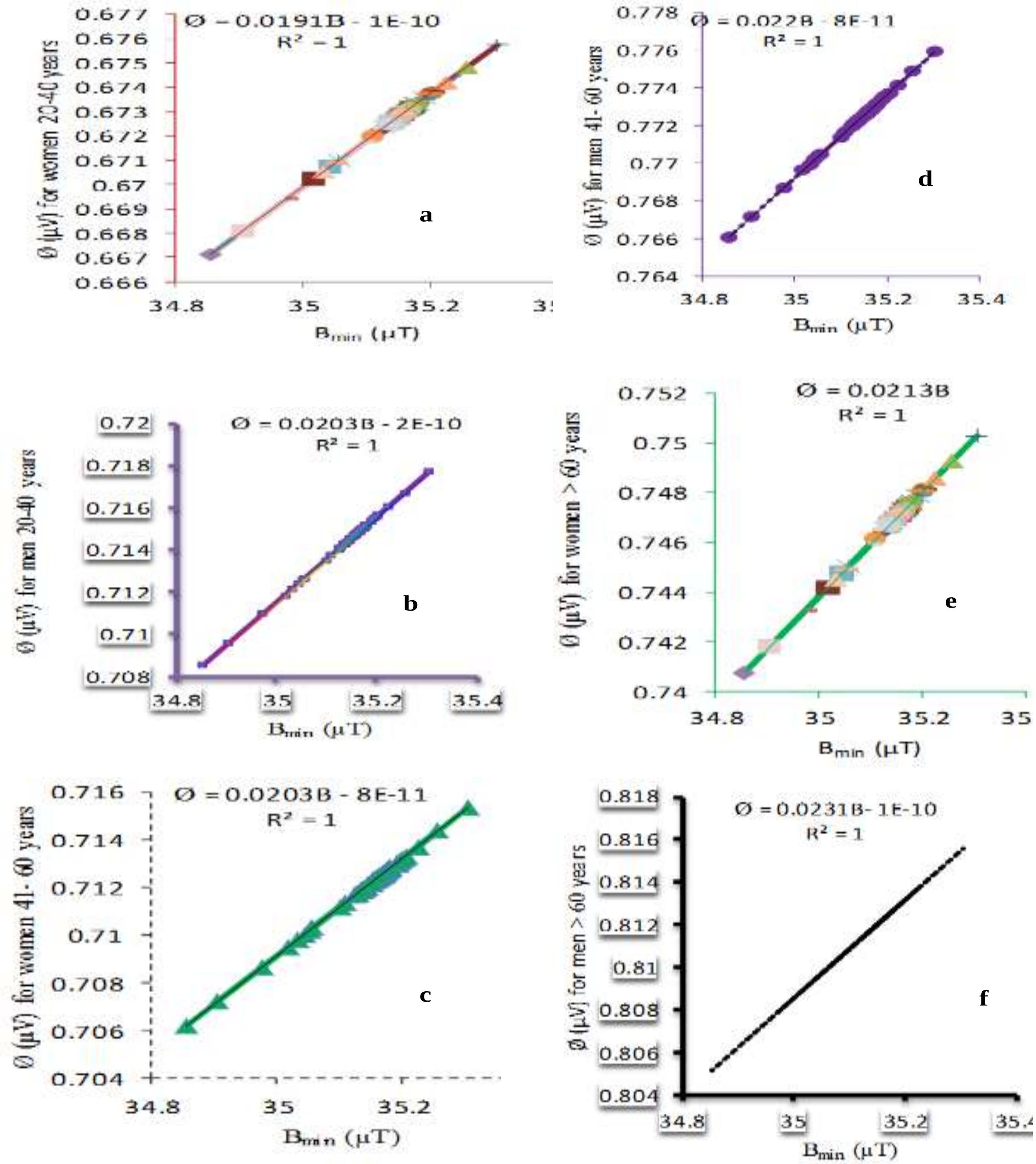

Figure 4. Potential-Minimum Magnetic Field Linear Curves Due to Different Diameters of The Aorta in Both Women and Men.

than 0.1 – 0.4 mT, may also alter the functioning of the pacemaker by inducing potential (Hall voltage) that may affect cardiac signals. Hall Effect principle has to do with the generation electrical voltage through an electrical conductor when the magnetic field is at right angle to the path of the current flow in the conductor or wire (Ling et al., 2016). The statistical hypothesis testing for significance of evidence indicates probability value as very much lower than 0.01 (1.1×10^{-205}, this is about zero) which is intended with the coefficient of determination and correlation coefficient of one, from regression analysis (Figures 4 and 5). Although the magnetic flux density is generally below the harmful value

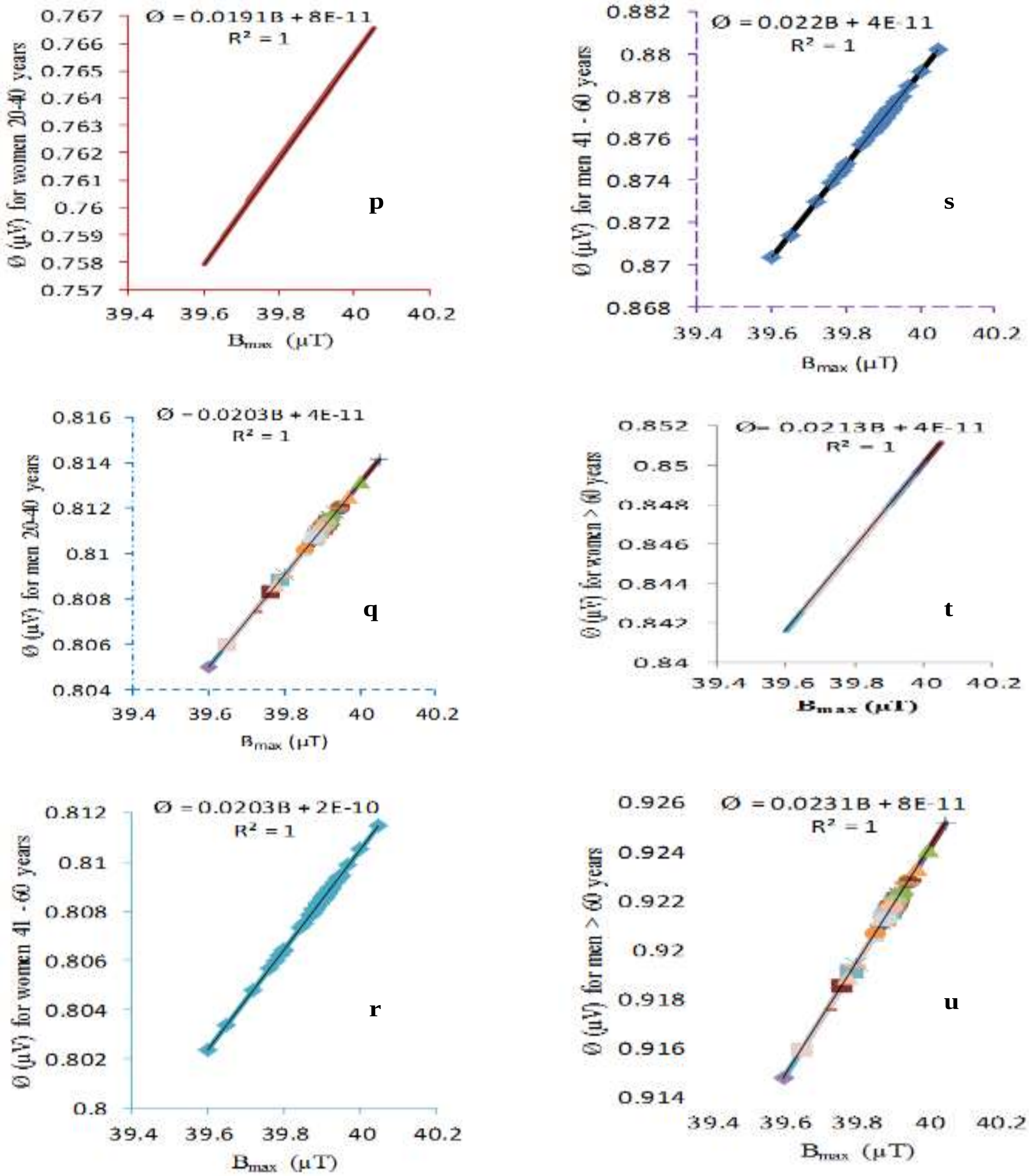

Figure 5. Potential-Maximum Magnetic Field Linear Curves Due to Different Diameters of The Aorta in Both Women and Men.

when comparing both the maximum and the minimum values to the distance of the home appliances responsible for emission of magnetic radiation, it is clearly shown that the spread of B is not precisely following any specific trend. However, in the minimum value trend in Figure 3a, the relatively high values are prominently seen in the southern part of the image map and sparingly seen in the northern part. In Figure 3b (maximum trend image map for B), high value is also relatively dominant in the southern part of the study area while the northern part of the study area has sparingly high value. This trend on the maps indicate that the rate of magnetic flux is dependent on the availability of the appliances emitting this radiation and constant emission can lead to excess flux that may be dangerous.

The total magnetic field strength as determined here for both minimum and maximum in all stations/cases are about 0.035 mT and 0.040 mT respectively. The average magnetic field strength obtained is (3.99093 ± 0.00512) x 10^{-5}T. These values are relatively lower than both minimum standards that would have cause problem (or malfunctioning) to the cardiac pacemaker of the heart. Therefore, Creek Town is very safe for those with these devices implanted in them. Care should also be taken to ensure that a safe minimum distance is observed were magnetic resonance imaging equipment, power transmission cables, high voltage distribution lines, transformer stations and other high voltage sources not considered in this investigation are present. This is because magnetic field decreases as the distance from the source increases; the best protective measure when the magnetic field is higher than these limits, is to consider moving away from strong field locations. When moving ionic charge carriers in the blood are exposed to a magnetic field, Lorentz force induces an electric potential (Ø) in the body. Equation 5 was employed to obtain the values of this potential and the results are included in Figures 4 and 5. These potential values relate with the velocity of the blood flow in the aorta (ascending), the magnetic field strength and the diameter of the aorta. Blood usually flow in the body from the heart to the left ventricle and enters the ascending aorta first, before other segments or branches of the aorta. The challenge here is that aorta is affected by sex and age. To take care of this or consider necessary precaution, we have determined the possible potential induced due to sex (women and men) and age (20 – 40 years, 41 – 60 years and greater than 60 years) which result in three different diameters of the aorta in these categories. Both minimum and maximum field strength values were used in order to compute the induced potential. The value of magnetic field strength plotted with corresponding expected induced potential value, resulted in a linear curve with correlation coefficient of 1.0 (Figures 4 and 5). From the graphs of Figure 4, the potential relates with magnetic field as:

Ø = 0.0191B - 1E-10 (Figure 4a) ...(6)

Ø = 0.0203B - 8E-11 (Figure 4c) ...(7)

Ø = 0.0213B (Figure 4e) ...(8)

Ø = 0.0203B - 2E-10 (Figure 4b) ...(9)

Ø = 0.0220B - 8E-11 (Figure 4d) ...(10)

Ø = 0.0231B - 1E-10 (Figure 4f) ...(11)

Also, from the graphs of Figure 5, the potential relates with magnetic field as

Ø = 0.0191B + 8E-11 (Figure 5p) ...(12)

Ø = 0.0203B + 2E-10 (Figure 5r) ...(13)

Ø = 0.0213B + 4E-11 (Figure 5t) ...(14)

Ø = 0.0203B + 4E-11 (Figure 5q) ...(15)

Ø = 0.0220B + 4E-11 (Figure 5s) ...(16)

Ø = 0.0231B + 8E-11 (Figure 5u) ...(17)

Subtracting or adding the second term to the first term of Equations 6 to 17 will still result in the potential (Ø) equal to the first term approximately. This is because the first term is very much greater than the second term; it is considered as a negligible value. The difference is clearly seen that the factors which influence the potential induced are the magnetic field, the velocity and the diameter of different sex and age group. The potential obtained for age group of men greater than 60 years is the highest (Equations 11 and 17) with average value of (8.671 ± 0.549) x 10^{-7}V. We also deduce that men within the ages of 40 – 60 years (Equations 10 and 16) whose average potential result gives (8.250 ± 0.523) x 10^{-7}V, could record a potential almost equal (or greater than) to those of women of greater than 60 years (Equations 8 and 14) (the average potential of this group is (7.977 ± 0.505) x 10^{-7}V) as well as men within 20 – 40 years old (Equations 9 and 15) whose average potential = (7.630 ± 0.483) x 10^{-7}V, comparable to women whose age group is 40 – 60 years old (Equations 7 and 13) (This group average potential = (7.606 ± 0.482) x 10^{-7}V). However, the least induced potential deduced from the graph is from women of 20 – 40 years age group (Equations 6 and 12); the average = (7.185 ± 0.455) x 10^{-7}V. Therefore, men pumped more blood from the heart due to their aortic diameter and show why they are stronger than women. During surgical operation, much larger aorta has the least successful operation and this is mostly observed among smoking patients. If smoking is avoided, most surgical operations will be successful because smokers are liable to die young or prematurely. The key threat influence is smoking and the danger of complication quickens beyond a diameter of 6 cm considering ascending aorta; 7 cm for the descending aorta. The risk of rupture, dissection, and death varies as 5 to 6.5% less than 6 cm and greater than 14% beyond 6 cm (Elefteriades, 2002). The risk of rupture rises with the diameter of the aorta though may also occur in small aorta (Pope et al., 1996).

0.5mT and 0.1mT are two minimum values of static and time varying magnetic field strength which will not reverse pacemaker to asynchronous mode. The average value of these two limits is 0.25mT = 2.5 x 10^{-4}T. The same diameters and velocity used to compute other hall voltages were also considered to determine a minimum potential due to this average correspondingly.

In order to compare our potential results, we generated an induced potential limit corresponding to the effect of the standard limit of magnetic field strength recommended for safety. As B_{mean} (standard limit) is 0.00025T, Ø due to $v_b$peak in women and men are 0.000004785V and 0.000005082V (20 – 40 years), 5.0655E-06V and 5.4945E-06V (40 – 60years), 0.000005313V and 0.000005775V respectively. Therefore, induced potentials computed do not post any threat to people with pacemaker in their hearts. This result may also indicate why the strength of a man is always greater than that of a woman of the same age and even more than some women who are older than him. A man should therefore, not be allowed in a game of strength or fight with a man. A newer Magnetic Resonance Imaging (MRI): safe Medtronic pacemaker is recommended so that in situation where a patient must undergo MRI scanning, this device could be programmed to lockout since it is furnished with Hall-effect senor controls, which function as a transducer to activate an electronic switch ON or OFF when triggered by a magnetic field (Jacob et al., 2011).

CONCLUSION

The strength of total magnetic field due to static or time-varying assessed in the area of study is about 0.04 mT. This finding result is significantly smaller to the standard. The environment is safe and conducive for all pacemakers of the heart or other implanted device patients. The expected induced potential is also less than the minimum expected potential investigated here due to the standard limit of the average of magnetic fields. This result is greatly affected by aortic diameter which depends on age and sex. We recommend safe Medtronic pacemaker for use as it has the component to enable and disable the signal control to avoid the pacemaker from reversing to asynchronous mode. Though the environment is conducive, patients should always observe a safe distance since magnetic field decreases with distance from the source. Distances closer to high powered-voltage and MRI sources which could interfere with the device, should be avoided to ensure it remains in synchronous mode. The rate of magnetic flux is dependent on the availability of the appliances emitting this radiation and constant emission can lead to excess flux that may be dangerous.

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