Covenant Journal of Informatics & Communication Technology Vol. 4 No. 2, Dec, 2016

An Open Access Journal, Available Online

Monitoring Cardiovascular Disease-Patients with Mobile Computing Technologies

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Abstract: Physicians and healthcare networks have been slow to adopt electronic medical records and to integrate medical data with the ubiquitous mobile device. Mobile and wearable systems for continuous health monitoring constitute a key technology in helping the transition of health care to a more proactive and affordable healthcare. Cardiovascular Disease (CVD) includes dysfunctional conditions of the heart, arteries, and veins that supply oxygen to vital life-sustaining areas/organs of the body. CVD singly accounts for about 40% of all deaths worldwide. Over 80 per cent of CVD deaths take place in low- and middle-income countries. An estimated 17.5 million people died from cardiovascular disease in 2005, and expected to top 20 million per year by 2015. By 2030, more than 23 million people will die annually from CVDs. CVDs' patients face risks of recurrent acute cardiovascular events, hospital re-admission, and unfavourable quality of life. Heart Failure, (HF), leads to death if not properly managed and supervised. Current treatments for Congestive Heart Failure (CHF) provide a limited palliative outcome. New technologies are now pertinent to generate high-dimensional data that provide unprecedented opportunities for unbiased identification of biomarkers that can be used to optimize pre-operative planning, with the goal of avoiding costly post-operative complications and prolonged hospitalization. Due to the crucial role of remote monitoring for CVD patients, significant efforts from research communities and industry to propose and design a variety of CVD monitoring devices have become imperative. This paper builds a proof-of-concept and presents a cardiovascular monitoring system, Cardiovascular Disease Management System (CVDMS), for real-time information on patient's heart health status with respect to his/her heart beat in hemodynamics computation towards reducing re-admission incidence problem. Administered 485 questionnaires and interviewed 12 cardiologists, 45 physicians, and 23 pharmacists to gather details on vital CVD parameters. 469 of 485 questionnaires (96.70%) were validly completed and returned, while 16 (3.30%) were not. Searched internet databases and cognate texts for literature. A mobile CVDMS for HF was developed using UML, MySQL Server 5.0, Java servlets, Apache Tomcat 6.0 server, microcontroller, and Ozeki sms server. Patient completes a questionnaire on a J2ME platform-based computing device that measures the heartbeat rate. Biological signals acquired by CVDMS are processed by microcontroller. Pulses are counted within a space of one minute to know heartbeat rate per minute. The CVDMS application gets the heartbeat reading, and if the heart rate is abnormal, a trigger is set enabling the Ozeki SMS Gateway to send an alert to patient's next-of-kin and cardiologist. CVDMS guarantees individual patient's direct involvement to closely monitor changes in his/her vital signs and provide feedback to maintain an optimal health status. Medical personnel get alerted when life-threatening changes occur in establishing proper communication between patient and cardiologist via sms. Hemodynamics computation could be performed with the parameters obtained from the data supplied by CVDMS as a cardiovascular intervention to save many lives and improve quality of life.

Keywords: artery stiffness; blood pressure; cardiologist; cardiovascular disease; heart attack; heart failure; hemodynamic volumetric parameters; hospital re-admission; hypertension; risk-factor.

1. Introduction

The cardiovascular system consists of heart, vessels, and blood. In a healthy person, the heart pumps the blood in vessels with synchronous pulses (HR) and pulse wave velocity (PWV). The source of power of life is the heart, and the blood nourishing the body constantly flows under her impetus. However, she also demands the nourishing of blood. Coronary artery, namely three blood vessels respectively located in the heart, can supply blood and oxygen to her. The coronary artery is the artery special for supplying blood to the heart. If cholesterol and other substances are accumulated in the blood vessels, the vascular cavity will be narrower or be blocked and the blood flow will be smooth and then be blocked to cause cardiac ischemia and a series of symptoms which are coronary heart disease, namely coronary atherosclerosis. Coronary heart disease (CHD) is also called as coronary atherosclerotic heart disease. The excessive fat deposition results in atherosclerosis and weakened elasticity. The mortality of human on cardiovascular and cerebrovascular diseases induced on the arterial vessel wall has exceeded 1 / 2 of the total mortality of population. Dangerous factors making the elasticity of coronary artery weakened are high blood fat, smoking, diabetes, obesity, high blood pressure, lack of physical activity, psychological overstrain, family history of coronary heart disease, oral contraceptive, etc. The force of blood flux, which is caused by heart beating, forms a pressure against blood vessels' walls. Blood pressure, (BP), is a vital measurement used by the physicians for diagnosing the health situation of subjects, and saving them from critical diseases or some dangerous circumstances, such as hypertension, hypotension, artery stiffness, coma or heart attack (Al-Jaafreh and Al-Jumaily, 2008). Cardiovascular Disease (CVD) includes dysfunctional conditions of the heart, arteries, and veins that supply oxygen to vital life-sustaining areas of the body like the brain, the heart itself, and other vital organs. Cardiovascular disease, including heart disease and stroke, remains the leading cause of death around the world. CVD being the prime cause of death among the elderly in industrialized countries is a major determinant of chronic disability. Cardiovascular diseases represent the main cause of death for people of developed countries, and frequently they may account for premature fatal outcomes even in the apparently healthy young. The morbid entities are mostly structural, affecting the major components of the heart (aorta, pulmonary artery, pericardium, coronary arteries, myocardium, endocardium and conduction system). Yet, most heart attacks and strokes could be prevented if it were possible to provide an easy and reliable method of monitoring and diagnostics. In particular, the early detection of abnormalities in the function of the heart, called arrhythmias, could be valuable for clinicians (Nataraj et al. 2012; Thiene and Basso, 2015). Bausch-Jurken and Kotchen (2015) asserted that American Heart Association (AHA) had estimated the total cost, both direct and indirect, of cardiovascular disease (CVD) and stroke in the United States to be $312.6 billion. AHA also projected the cost of cardiovascular care to increase to an estimated $818.1 billion by 2030. AHA has attributed 40.6% of CVD to hypertension, 13.7% to smoking, 13.2% to poor diet, 11.9% to inactivity, and 8.8% to abnormal blood glucose. Walsh et al. 2014 reported physicians and healthcare networks have been slow to adopt electronic medical records and to integrate medical data with the ubiquitous mobile device. The need for cardiac diagnostics, like electrocardiography (ECG) holters or cardiac event recorder resulted in creation of such devices about 50-years ago (Wcislik et al. 2015). In cardiovascular prevention, there is classically a small number of cardiovascular risk factors to treat, such as hypertension, diabetes, hyperlipidemia and smoking excess, which are widely detected and treated. Recently, it has been widely recognized that new mechanical factors should be detected and treated and involves specifically pulsatile arterial hemodynamic (PAH) parameters such as: arterial stiffness, pulse pressure, and, to a lesser extent, augmentation index and pulse pressure amplification.

Mobile and wearable systems for continuous health monitoring are a key technology in helping the transition of health care to a more proactive and affordable healthcare. Wearable health monitoring systems allow an individual to closely monitor changes in her or his vital signs and provide feedback to help maintain an optimal health status. If integrated into a telemedical system, these systems can even alert medical personnel when life-threatening changes occur. Patients can benefit from continuous long-term monitoring as a part of a diagnostic procedure, can achieve optimal maintenance of a chronic condition, or can be supervised during recovery from an acute event or surgical procedure (Milenković et al. 2006).

2. Literature Survey

Methods of medical diagnosis are continuously being improved and extended. Ulucam, 2012, identified the most well-known CVD risk factors in the elderly as high blood pressure (BP), wide pulse pressure, age (male > 55, women > 65), smoking, dyslipidemia (total cholesterol >190 mg/dL, or LDL cholesterol >115 mg/dL, or HDL cholesterol in men <40 mg/dL, female <46 mg/dL, triglyceride >150 mg/dL), fasting glucose 102-125 mg/dL, abnormal glucose tolerance test, diabetes mellitus, abdominal obesity (abdominal circumference: M > 102 cm, F > 88 cm), and a family history of premature CVD disease. Unhealthy lifestyle behaviours, including smoking, physical inactivity, hazardous alcohol consumption and low intake of fruit and vegetables have been shown to contribute to the development of coronary heart disease (CHD), which remains a leading cause of death worldwide (Dale et al. 2014). Kilty and Prentice, 2012 and Kong and Choi, 2012 reported CVDs have become one of the leading causes of morbidity and premature mortality in men and women in the industrialized world and many developing countries. The leading global risks for mortality in the world were high blood pressure (13% of global deaths), tobacco use (9%), high blood glucose (6%), physical inactivity (6%) and overweight or obesity. It was also predicted that by the year 2020, CVDs would be the leading cause of death in the entire world. Heart attacks and CHD are primarily caused by atherosclerosis, where a narrowing and hardening of the arteries result from an accumulation of fat and cholesterol deposits called plaque. Gaziano et al. 2015 documented cardiovascular disease (CVD) to have emerged as the single most important cause of death worldwide. In 2010, CVD caused an estimated 16 million deaths and led to 293 million disability-adjusted life-years (DALYs) lost — accounting for approximately 30% of all deaths and 11% of all DALYs lost that year. Like many high-income countries (HICs) during the past century, now low- and middle-income countries (LMICs) are seeing an alarming and accelerating increase in CVD rates.

Haslam and James, 2005 found CVD, with an emphasis on congestive heart failure, was being studied using proteomics and continues to be increasingly relevant to an aging population. Recently, NCD has become an important cause of mortality & morbidity in developing countries. Diabetes Mellitus (DM) and hypertension are major predisposing factors to CVD. Upsurge of DM & hypertension is propelled by growing prevalence of overweight and obesity worldwide, especially among children & adolescents. Heart failure, (HF), a condition where the heart is no longer able to maintain adequate blood circulation, results from myocardial dysfunction that impairs the heart's ability to circulate blood at a rate sufficient to maintain the metabolic needs of peripheral tissues and various organs. Heart failure is a relatively common clinical disorder, estimated to affect more than 2 million patients in the United States. About 400,000 new patients develop congestive heart failure (CHF) each year. Morbidity and mortality rates are high; annually, approximately 900,000 patients require hospitalization for CHF, and up to 200,000 patients die from this condition. The average annual mortality rate is 40–50% in patients with severe (New York Heart Association (NYHA) class IV) heart failure (Deedwania, 2007). Some causes of heart failure include coronary artery disease, valvular disease, and myocardial infarction. Heart failure is a common disease in the Western world with a high prevalence and steadily rising incidence. Two major reasons contribute to the increasing incidence in this part of the world: firstly, better treatment of cardiovascular disease, in particular of acute ischemic events, such as myocardial infarcts which keep more people alive, however often at the cost of damaged, malfunctioning heart muscle, the first step on the road to heart failure; and secondly, an ageing population – heart failure is typically a disease of the elderly. The average age of the heart failure patient in the community is 74-75 years. Average prevalence of heart failure is 2-2.5% overall, increasing to >10% in octogenarians; up to 14 million inhabitants of Europe have heart failure; and average incidence of heart failure is 15/1000 inhabitants in people ≥55 years, but increases significantly in the elderly. It is now recognized that approximately 40% of all heart failure patients may have a preserved pump function of the left chamber (left ventricle- LV) of the heart. Patients with HF have a worse quality of life than those with almost any other chronic disease including bronchitis/emphysema, kidney failure and arthritis. Chronic diseases are common and costly, yet they are also among the most preventable health problems (WHFS, 2010).

2.1 Therapy and Treatment

reatment of cardiovascular disorders is one of the most highly evidence-based area of medicine and pharmacy practice. A careful patient history and physical examination are extremely important in diagnosing cardiovascular disease and should be done prior to any test. Heart sounds and heart murmurs are important in identifying heart valve abnormalities and other structural cardiac defects. Elevated jugular venous pressure is an important sign of heart failure and may be used to assess severity and response to therapy (Talbert, 2005). Accounting for more than 40% of deaths each year, cardiovascular disease remains the leading cause of mortality in the United States. Contributing to this mortality are two key conditions: myocardial infarction and congestive heart failure. Myocardial infarction triggers the formation of scar tissue, which is one of the causes of congestive heart failure. Current treatments for congestive heart failure provide a limited palliative outcome; therefore, myocardial infarction and congestive heart failure could benefit substantially from cell therapies. Such therapies could benefit not only patients but also the healthcare system in terms of burden of resources and financing (Sage, 2008). Improvements in health care and treatment of diseases have led to an increase in life expectancy in developed countries. However, this achievement has also inadvertently increased the prevalence of chronic illnesses such as cardiovascular disease, adding to the growing burden of health care cost globally. Ironically, the recent improvements in treating ischemic disease have increased the number of patients living with congestive heart failure, the fastest-growing segment of cardiovascular disease. Unfortunately, this prevalence trend is expected to escalate in the foreseeable future. Cardiovascular disease remains one of the main problems in contemporary health care worldwide, accounting for approximately one third of the world's total death (Poole-Wilson, 2005). Although >80% of global burden of CVD occurs in developing countries, however, knowledge on the risk factors is largely derived from developed countries (Parvez, 2007). Kilty and Prentice (2012)'s model of CVD treatment as presented in Figure 1 reports that there is strong evidence that cardiovascular risk factors begin and can be identified in childhood and adolescence that influence the development of CVD in adulthood. They called for interdisciplinary and interprofessional teams of researchers, clinicians, educators, parents and care providers to work together on this health issue and inform each other of their outcomes.

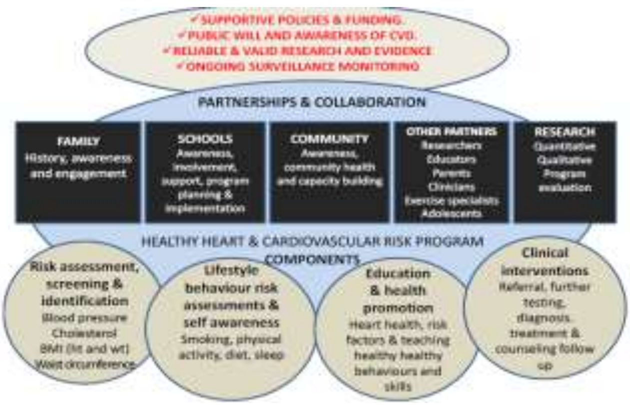

Figure 1 Comprehensive Treatment CVD Model (Kilty and Prentice, 2012)

New technologies are pertinent to generate high-dimensional data that provide unprecedented opportunities for unbiased identification of biomarkers that can be used to optimize pre-operative planning, with the goal of avoiding costly post-operative complications and prolonged hospitalization (Aggeli et al; 2014). Mobile technologies have been confirmed to offer the ability to connect patients with their doctors, care-givers and loved ones and enable timely health monitoring which suggests improved patient engagement and better health outcomes. Mobile technology provides aid in providing access to information, helping to lower costs, facilitating remote care and increasing efficiencies by connecting patients to their providers virtually anywhere. Mobile health applications and services are becoming an essential tool in extending health care resources around the world (West, 2013). Smart phone apps and wearable sensors are promising for improving cardiovascular health behaviors, preliminary data suggest. Self-monitoring is a key facet of changing behavior to prevent and manage heart health. Smartphone apps and wearable sensors have the potential to encourage positive change (AHA, 2015). Boursalie *et al* 2015 presented M4CVD: a Mobile Machine Learning Model for Monitoring Cardiovascular Disease, a system designed specifically for mobile devices that facilitates monitoring of cardiovascular disease (CVD). M4CVD using wearable sensors collects observable trends of vital signs contextualized with data from clinical databases. Instead of transferring the raw data directly to the health care professionals, M4CVD performs analysis on the local device by feeding the hybrid of collected data to a support vector machine (SVM) to monitor features extracted from clinical databases and wearable sensors to classify a patient as "continued risk" or "no longer at risk" for CVD. These statistics suggest that health care needs a major shift toward more scalable and more affordable solutions including measuring the rate of heartbeat using mobile computing technologies to monitor and ensure proper communication between the patient and cardiologist addressed in this paper.

2.2 Control of Cardiovascular System: Hemodynamic volumetric parameters

Hemodynamics has been defined as the study of the relationship among physical factors affecting blood flow through the vessels. Blood flow is a function of pressure difference and resistance. Blood flow (F) through a blood vessel is determined by two main factors: (1) pressure difference (ΔP) between the two ends of the vessel and (2) the resistance (R) to blood flow through the vessel (Figure 2).

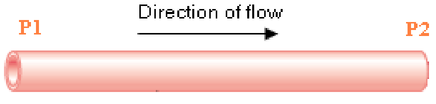

Figure 2 Blood flow through a blood vessel (Nasimi, 2012)

The equation relating these parameters is:

$$F = \Delta P/R \quad (1)$$

This equation is called Darcy's law or Ohm's law.

Flow (F) is defined as the volume of blood passing each point of the vessel in one unit time. Usually, blood flow is expressed in milliliters per minute or liters per minute, but it is also expressed in milliliters per second. Pressure which is the force that pushes the blood through the vessel is defined as the force exerted on a unit surface of the wall of the tube perpendicular to flow.

Pressure is expressed as millimeters of mercury (mmHg). Since the pressure is changing over the course of the blood vessel, there is no single pressure to use; therefore the pressure parameter used is pressure difference (ΔP), also called pressure gradient, which is the difference between the pressure at the beginning of the vessel (P1) and the pressure at the end of the vessel (P2), i.e. ΔP = P1 - P2. As seen in the Darcy's law, ΔP is the cause of the flow; with no pressure difference there would be no flow. The pressure energy is produced by the ventricle and it drops throughout the vessel due to resistance. In other words, resistance is the cause of the pressure drop over the course of a vessel. Resistance is how difficult it is for blood to flow from point 1 to point 2. Resistance impedes flow and it is a measure of interactions between flowing particles (including molecules and ions) themselves and interactions between flowing particles and the wall of the vessel.

As seen Darcy's law, resistance is the impeding cause of the flow; the bigger the resistance the lesser the flow. If the resistance is Δ (complete closure of the vessel) there will be no flow.

The resistance equation is:

$$R = 8\eta L / \pi r4 \qquad (2)$$

where η = fluid viscosity

L = vessel length

r = inside radius of the vessel.

Viscosity represents the interactions between flowing particles themselves and radius represents the interactions between flowing particles and the wall of the vessel. The units of viscosity are Pa·s = Ns/m^2, or Poise (dynes·s/cm^2), with 1 Pa·s = 10 Poise (Nasimi, 2012).

Rudenko et al. 2012 has asserted the foundation of hemodynamics as the phase mode of the heart performance such that in one beat, the heart changes its shape ten times that corresponds to the heart cycle phases. The most efficient way is to evaluate the status of hemodynamics not only by values of integral parameters, i.e., stroke and minute volumes, but also phase-related volumes of blood entering or leaving the heart in the respective phase in a cardiac cycle. The final formulae for calculating the volumes of blood in the phase of rapid and slow ejection, symbolized as PV3 and PV4, respectively, are as follows:

$$PV3=S\bullet(QR+RS)^2 \bullet f_1(\alpha) \bullet (f_2(\alpha)+f_3(\alpha,\beta,\gamma,\delta)) \text{ (ml)}; \quad (1)$$

$$PV4=S\bullet (QR+RS)^2\bullet f_1(\alpha)\bullet f_4(\alpha,\beta,\gamma,\delta) \text{ (ml)}, \quad (2)$$

where S - cross-section of ascending aorta;

QR – phase duration according to ECG curve;

RS – phase duration according to ECG curve;

$$f_1(\alpha)= 22072.5((5\alpha - 2)^3 - 27) / ((5\alpha - 2)^5 - 243);$$

$$f_2(\alpha)= (\alpha^5 - 1)/2;$$

$$f_3(\alpha,\beta,\gamma,\delta)= \frac{1}{8}(\frac{10}{3}(4\alpha^2 - \delta^2)(\beta^3 - \alpha 3) +5\chi\delta(\beta^4 - \alpha^4) - 2\chi^2(\beta^5 - \alpha^5);$$

$$f_4(\alpha,\beta,\gamma,\delta)= \frac{1}{8}(\frac{5}{3}(\delta^2 - 8\alpha^2)(\beta^3 - \alpha^3) + 7.5\chi\delta(\beta^4 - \alpha^4) + 3\chi 2(\beta^5 - \alpha^5);$$

$$\alpha = \frac{(1+ Em)^{0.2}}{QR+ RS};$$

$$\beta = \frac{(1+ Em+ Er)^{0.2}}{QR+ RS};$$

$$\chi = 2(\alpha - 1) / (\beta - \alpha);$$

$$\delta = \alpha(2 + \chi).$$

Stroke volume, SV, is calculated by an equation as given below:

$$SV = PV3+ PV4=S\bullet (QR+RS)^2\bullet f_1(\alpha)\bullet (f_2(\alpha) + f_3(\alpha,\beta,\gamma,\delta)+f_4(\alpha,\beta,\gamma,\delta)) \text{ (ml)} \quad (3)$$

The minute stroke is computed as follows:

$$MV = SV\bullet HR \text{ (l/min)} \quad (4)$$

In similar way calculated are other phase-related volumes of blood as listed below:

PV1 – volume of blood entering the ventricle in premature diastole;

PV2 – volume of blood entering the ventricle in atrial systole;

PV5 – volume of blood pumped by ascending aorta as peristaltic pump.

So, the main parameters in hemodynamics are 7 volumes of blood entering or leaving the heart in different heart cycle phases. They are as follows: stroke volume SV, minute volume MV, two diastolic phase-related volumes PV1 and PV2, two systolic phase-related volumes PV3 and PV4, and PV5 as volume of blood pumped by the aorta. These hemodynamic parameters should be used mainly in order to evaluate eventual deviations from their normal values, if any. The limits of normal values of hemodynamic parameters are not conditional, and they have their respective calculated values. With respect to the normal values (the required parameters) in hemodynamics, they have been taken on the basis of the known data on ECG waves, intervals and segments for adults from the literature sources as given below:

1. The upper and lower limit of the QRS complex values:

$QRS_{max} = 0.1$ s;

$QRS_{min} = 0.08$ s.

2. The upper and lower limit of the RS complex values:

$RS_{max} = 0.05$ s;

$RS_{min} = 0.035$ s.

3. The normal value of interval QT in every specific cardiac cycle is determined from the Bazett formula as follows:

QT = 0.37 RR0.5 s (for men);

QT = 0.4 RR0.5 s (for women).

4. Normal value PQ is calculated from a formula as indicated below:

$PQ = 1 / (10^{-6}\ \ 638,44\ \ HR^2 + 9,0787)$ s.

This equation has been produced according to the method of approximation of normal values PQ, as known from the sources, considering their dependence on heart rate (HR) (Rudenko et al. 2012).

Hemodynamic instability is most commonly associated with abnormal or unstable blood pressure (BP), especially hypotension, or more broadly associated with inadequate global or regional perfusion. Inadequate perfusion may compromise important organs, such as heart and brain, due to limits on coronary and cerebral auto regulation and cause life-threatening illnesses, or even death. Therefore, it is crucial to identify patients who are likely to become hemodynamically unstable to enable early detection and treatment of these life-threatening conditions (Cao et al. 2008). Modern intensive care units (ICU) employ continuous hemodynamic monitoring (e.g., heart rate (HR) and invasive arterial BP measurements) to track the state of health of the patients. However, clinicians in a busy ICU would be too overwhelmed with the effort required to assimilate and interpret the tremendous volumes of data in order to arrive at working hypotheses. Consequently, it is important to seek to have automated algorithms that can accurately process and classify the large amount of data gathered and to identify patients who are on the verge of becoming unstable (Cao *et al*. 2008). Modern ICUs are equipped with a large array of alarmed monitors and devices which are used to try to detect clinical changes at the earliest possible moment so as to prevent any further deterioration in a patient's condition. The effectiveness of these systems depends on the sensitivity and specificity of the alarms, as well as on the response of the ICU staff to the alarms. However, when large numbers of alarms are either technically false, or true, but clinically irrelevant, response efficiency can be decreased, reducing the quality of patient care and increased patient (and family) anxiety (Nataraj *et al*. 2012).

3. Statement of the Problem

Heart Failure (HF) is a leading cause of hospitalization for people 65 years of age and older, and rates of hospital readmission within 6 months range from 25% to 50%. HF is managed by patients suffering from it visiting the doctor regularly for check up and treatment. Patients are not fully involved in some vital tasks, which if they could do for themselves would ease the doctors of some work.

4. Methods

We administered 485 questionnaires and interviewed 12 cardiologists, 45 physicians, and 23 pharmacists. Pertinent questions during the data collection phases centred on cardiovascular parameters including Blood Viscosity, Cholesterol Crystal, Blood Fat, Vascular Resistance, Vascular Elasticity, Myocardial Blood Demand, Myocardial Blood Perfusion Volume, Myocardial Oxygen Consumption, Stroke Volume, Left Ventricular Ejection Impedance, Left Ventricular Ejection Impedance, Left Ventricular Effective Pump Power, Coronary Artery Elasticity, Coronary Perfusion Pressure, Cerebral Blood Vessel Elasticity, and Brain Tissue Blood Supply Status. Cognate registries including Cardiac Arrest Registry to Enhance Survival (CARES), the Cardiovascular Research Network (CVRN), the National Cardiovascular Data Registry (NCDR), the International Registry of Aortic Dissection (IRAD), and the Global Registry for Acute Cardiac Events (GRACE) were consulted to collect information on cardiovascular disease. Literature databases such as MEDLINE, APAIS, Google Scholar and the Clinicians Health Channel were searched. Search terms used included “cardiovascular*”, “mortality*”, “cardiac”, “heart*”, “blood*”, “non-communicable*”, “hyperten*”, “myocardial*”, and “risk factor”.

As guided by international standards of the Institute of Medicine (IOM), detailed information on chronic conditions—including cardiovascular disease, diabetes, and respiratory health and disease—were collected by the administered questionnaire, and participants were assisted to undergo comprehensive dietary interviews and body measurements. The cardiologists, by standard practice, undertook physical examination that included several measures relevant to CVD and respiratory diseases, including blood pressure and spirometry, as well as cardiovascular fitness, body mass index, and body composition. Relevant biomarkers include cholesterol and triglyceride measures, C-reactive protein, and fasting plasma glucose. In addition to interviews with cardiologists to gather cognate questions, this project employed Unified Modeling Language (UML)’s use case, sequence, collaboration diagrams to formalize the functional requirements / interaction between a patient and a cardiologist as shown in Figure 3.

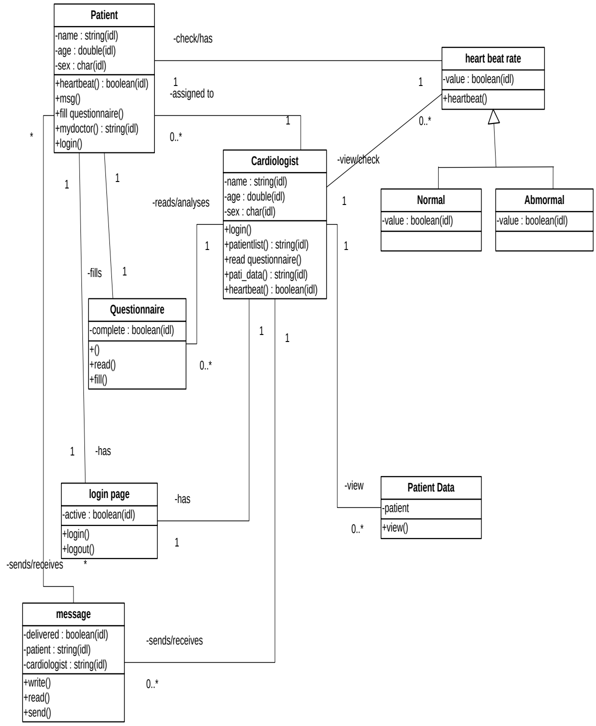

Figure 3 System Class Diagram of the CVDMS

The resulting framework was implemented on Edition Java 2 Platform (J2ME), MySQL Server 5.0, Java servlets, Apache Tomcat 6.0 server, and Ozeki sms server for emergency sms. Cardiovascular Diseases Management System (CVDMS) has modules designed for the patient's end to aid proper monitoring by the cardiologist and proper communication with the cardiologist.

5. Results

469 of 485 questionnaires (96.70%) were validly completed and returned, while 16 (3.30%) were not. Cardiovascular parameters normal range values (lower bound, median, and upper bound) confirmed from cardiologists are as presented in Figure 4.

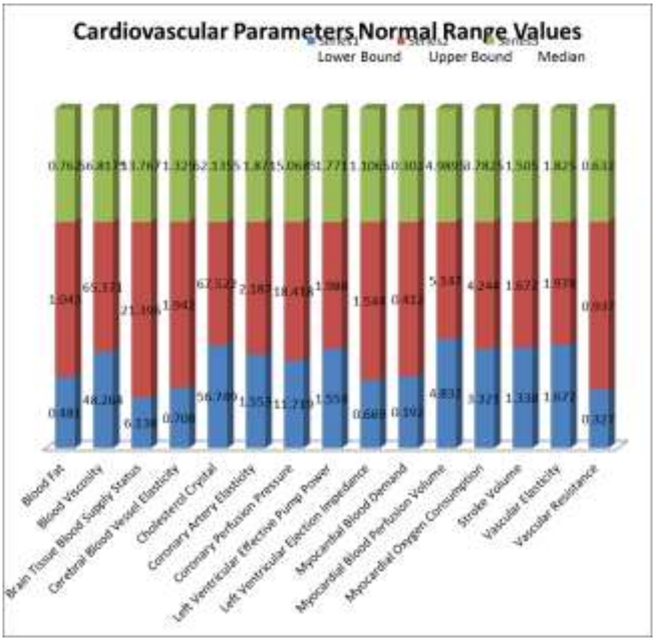

Figure 4 Cardiovascular Parameters Normal Range Values

Cardiologists confirmed, among other pertinent things, that Myocardial Oxygen Consumption (the milliliter value of oxygen consumption of heart per minute) is influenced by: (1) Heart rate: the heart rate is fast, and the HOV is great; (2) Myocardial contractility: the cardiac contractility is strong, and the HOV is great; and (3) Myocardial contraction time: the longer the contraction time is, the greater the HOV is. Thus, low oxygen consumption and high cardiac work are the best state. High blood pressure patients with high viscosity are prone to have cerebrovascular accidents, such as stroke and other phenomena; coronary heart disease patients with high viscosity are prone to have myocardial infarction and so on. Increase is in direct proportion to the length of blood vessels, and is in inverse proportion to the caliber of blood vessels. The increase of vascular resistance is seen in mildly elevated systolic and diastolic blood pressure, mild hypertension, insomnia with deficiency of heart and spleen, phlegm-heat internal confusion type insomnia, etc. Decline is seen in mildly declined systolic and diastolic blood pressure, mild hypotension, Yin deficiency and Huo exuberance type insomnia, etc. In a case of a 59year-old male, 85kg and 175cm height, the measurements collected were as shown in Figures 5, 6, and 7 to determine the risk level (severe partial fat).

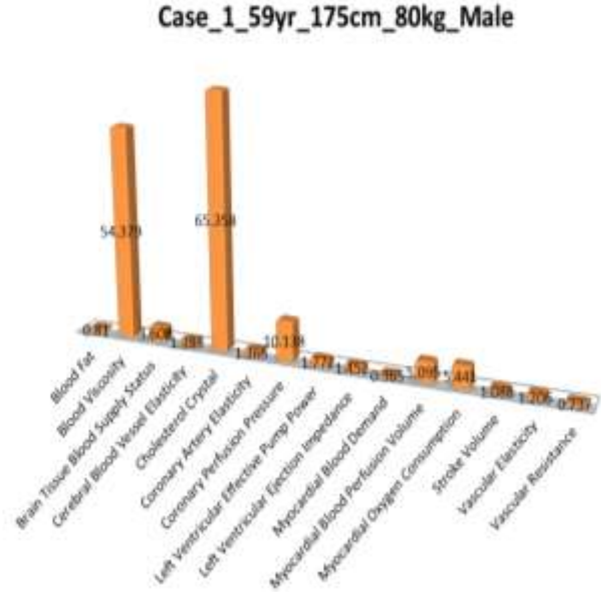

Figure 5 Cardiovascular Parameters actual measurements for a 59-yr-old, 175cm, 80kg male

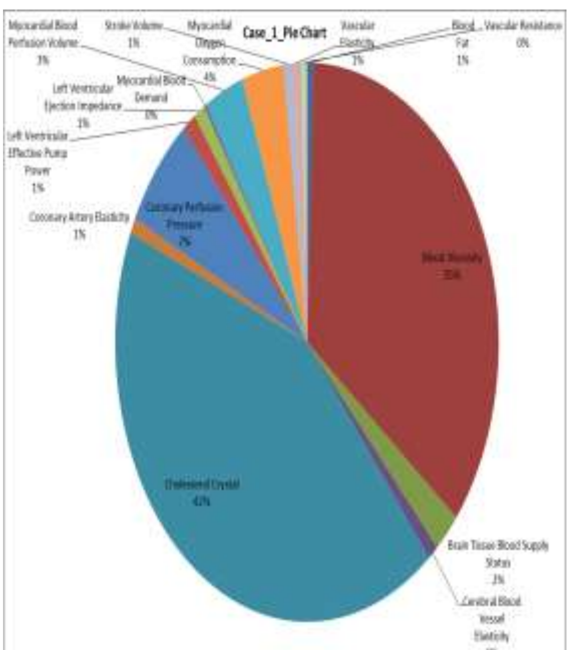

Figure 6 Pie Chart of Cardiovascular Parameters actual measurements for a 59-yr-old, 175cm, 80kg male

(Cardiovascular and Cerebrovascular) Analysis Report Card

Name: Omogbadegun Sex: Male Age: 59
Figure: Severe partial fat(175cm,80kg) Testing Time: 2012-03-03 15:02

Actual Testing Results

Testing Item	Normal Range	Actual Measurement Value	Testing Result
Blood Viscosity	48.264 - 65.371	54.379	Normal (-)
Cholesterol Crystal	56.749 - 67.522	63.338	Normal (-)
Blood Fat	0.481 - 1.043	0.81	Normal (-)
Vascular Resistance	0.327 - 0.937	0.737	Normal (-)
Vascular Elasticity	1.672 - 1.978	1.200	Moderately Abnormal (++)
Myocardial Blood Demand	0.192 - 0.412	0.365	Normal (-)
Myocardial Blood Perfusion Volume	4.832 - 5.147	5.093	Normal (-)
Myocardial Oxygen Consumption	3.321 - 4.244	5.441	Mildly Abnormal (+)
Stroke Volume	1.338 - 1.672	1.088	Mildly Abnormal (+)
Left Ventricular Ejection Impedance	0.669 - 1.544	1.432	Normal (-)
Left Ventricular Effective Pump Power	1.554 - 1.988	1.772	Normal (-)
Coronary Artery Elasticity	1.553 - 2.187	1.365	Mildly Abnormal (+)
Coronary Perfusion Pressure	11.719 - 18.418	10.138	Moderately Abnormal (++)
Cerebral Blood Vessel Elasticity	0.708 - 1.942	1.383	Normal (-)
Brain Tissue Blood Supply Status	6.138 - 21.396	3.608	Mildly Abnormal (+)

Reference Standard: **- Normal + Mildly Abnormal ++ Moderately Abnormal +++ Severely Abnormal**

Blood Viscosity:	48.264-65.371(-)	65.371-69.645(+)
	69.645-73.673(++)	>73.673(+++)
Cholesterol Crystal:	56.749-67.522(-)	67.522-69.447(+)
	69.447-74.927(++)	>74.927 (+++)
Blood Fat:	0.481-1.043(-)	1.043-1.669(+)
	1.669-1.892(++)	>1.892(+++)
Vascular Resistance:	0.327-0.937(-)	0.937-1.543(+)
	1.543-1.857(++)	>1.857(+++)
Vascular Elasticity:	1.672-1.978(-)	1.672-1.511(+)
	1.511-1.047(++)	<1.047(+++)
Myocardial Blood Demand:	0.192-0.412(-)	0.412-0.571(+)
	0.571-0.786(++)	>0.786(+++)
Myocardial Blood Perfusion Volume:	4.832-5.147(-)	4.177-4.832(+)
	4.029-4.177(++)	<4.029(+++)
Myocardial Oxygen Consumption:	3.321-4.244(-)	4.244-5.847(+)
	5.847-6.472(++)	>6.472(+++)
Stroke Volume:	1.338-1.672(-)	0.647-1.338(+)
	[illegible]	<0.[illegible](+++)
Left Ventricular Ejection Impedance:	0.669-1.544(-)	1.544-2.037(+)
	2.037-2.417(++)	>2.417(+++)
Left Ventricular Effective Pump Power:	1.554-1.988(-)	1.076-1.554(+)
	0.507-1.076(++)	<0.507(+++)
Coronary Artery Elasticity:	1.553-2.187(-)	1.183-1.553(+)
	0.983-1.183(++)	<0.983(+++)
Coronary Perfusion Pressure:	<8.481(+++)	8.481-11.719(++)
	18.418-21.274(++)	>21.274(+++)
Cerebral Blood Vessel Elasticity:	0.708-1.942(-)	0.473-0.708(+)
	[illegible]	<0.[illegible](+++)
Brain Tissue Blood Supply Status:	6.138-21.396(-)	3.219-6.138(+)
	1.214-3.219(++)	<1.214(+++)

Figure 7 cardiovascular and Cerebrovascular Analysis Report Card

We also gathered from the cardiologists that stroke volume (the blood volume output by the heart in beat each time) are equally influenced by: (1) The effective circulating blood volume (BV): when the blood volume is insufficient, the returned blood volume is little, and the SV is reduced; (2) The weakening of myocardial contractility: the contractility is low, and the pressure is low, so the ejected blood volume is less; (3) The extent of ventricular filling: In range of myocardial elasticity, the greater the degree of filling is, the stronger the retraction is, and the SV is increased. The normal heart chamber capacity is 173ml, but not all of the blood is ejected. The blood volume in the left ventricle is about 60% -70% of the total capacity, being about 125ml or so; (4) The size of peripheral vascular resistance (PR). The PR is large, and then the SV is reduced; the PR is small, and then the SV is increased; and (5) Ventricle wall movement. When the ventricle is contracted, the cardiac muscle is in coordinated movement. If the myocardial contraction is not coordinated, the SV is reduced. For instance, some patients with myocardial infarction have part of infarction, so the myocardial contractility is inconsistent and the SV is reduced. However, under normal circumstances, the ventricle wall movement can not be abnormal.

Figure 8 presents the login module for proper authentication of the user of this application, precisely the patient. The patient is given a list of options specifying the various functions that can be performed by the application on the patient's end.

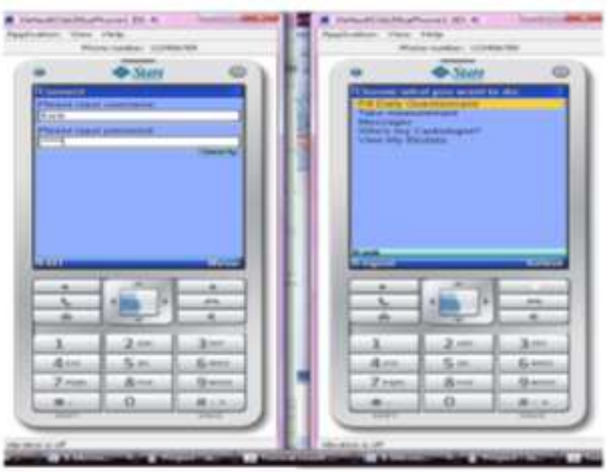

Figure 8 Login Menu module

As part of the cardiologist's monitoring exercise, he needs to have a daily report on the patient's health. As such, this module enables the patient fill a questionnaire daily as shown in Figure 9 in order to keep the cardiologist abreast of the patient's health status. The questions to be filled are basic general questions that help doctors in determining the general state of the patient's heart.

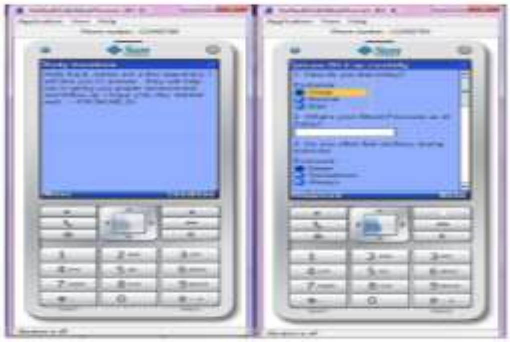

Figure 9 Daily Questionnaire & its Filling

After filling the questionnaire, a confirmation screen is displayed as shown in Figure10.

Figure 10 Screenshot showing the confirmation screen

Figure 11 provides help for the patient to send and receive vital messages to and from the cardiologist. This is also needed for proper monitoring of a patient and as such management of the cardiovascular disease.

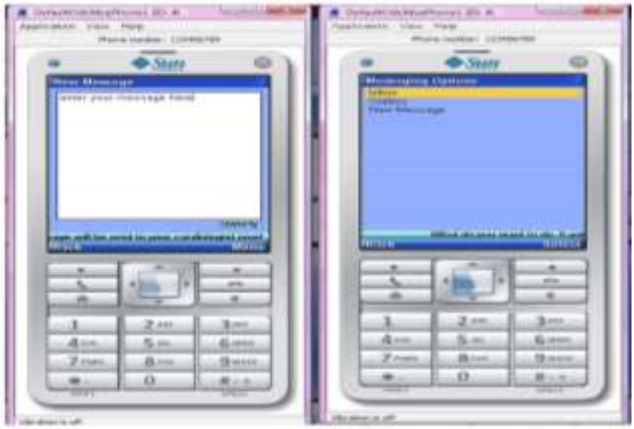

Figure 11 New Message screen / Messaging Option

A patient can view his message inbox (messages sent by the doctor to the patient), his message outbox (messages sent from the patient to the cardiologist). The CVDMS also provides an avenue for sending messages pertaining to health issues to the cardiologist.

The *Take Measurement Module* incorporates the Bluetooth technology to receive the rate of the patient's heartbeat from the CVDMS heart monitoring device as shown in Figure 12.

The device which acts as a slave finds the mobile phone and the service it offers, then sends the data to the mobile phone which acts as the master. The Java Bluetooth API plays an important role here as it enables better and easy communication between both Bluetooth devices.

Figure 12 Screenshot of the introduction to commence heartbeat reading

After taking the measurement, a java servlet is called to determine if the heart rate is within the normal range. If not, a message is stored in the ozekimessageout table and tagged as “send”. This means that the message is pending. The Ozeki SMS Gateway is configured to check the ozekimessageout table every 5 seconds to check for pending messages. In case of pending messages, the server sends an emergency sms to the phone of the next of kin, the cardiologist and the hospital. This will ensure proper monitoring and management of the cardiovascular disease. The patient can view the biodata of both himself and his cardiologist’s as shown in Figure 13.

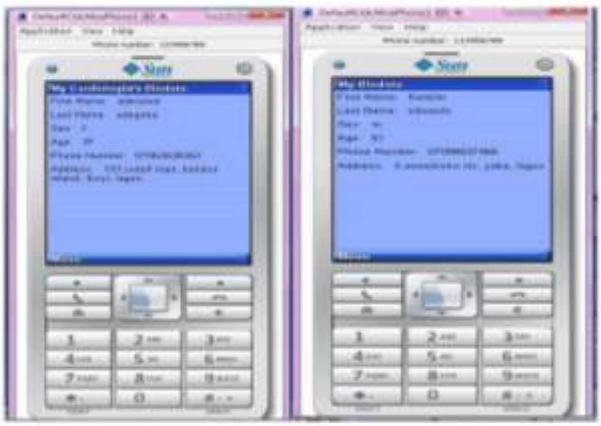

Figure 13 Screen shots of Cardiologist's & Patient's Biodata

5.1 The CVDMS Monitoring Device

In order to take proper reading and measurement of the heartbeat, a microcontroller was used for processing and an output device called the Liquid Crystal Display(LCD) was used to display the heartbeat rate. The signals sent to the green LED, an indicator for the heartbeat, was sent to an STC 8051 microcontroller and the pulses were counted within a space of one minute so as to know the rate of heartbeat per minute. After determining the rate, the value is then displayed on the LCD. This was first simulated using the ISIS 7 Professional and the result’s screenshot is shown in Figure 14.

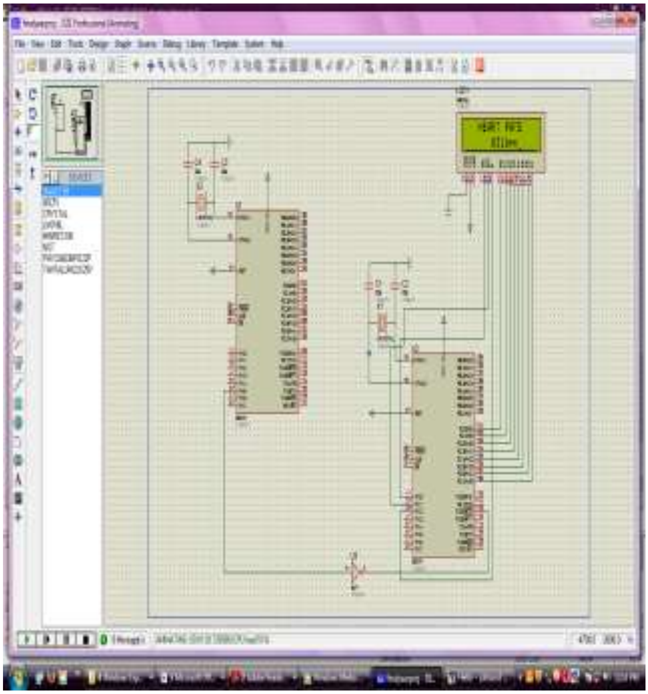

Figure 14 Simulation of microcontroller interfaced with LCD (CVDMS heart monitor)

When the mobile application gets the heartbeat reading using its Bluetooth technology, if the heart rate is abnormal, a trigger is set to enable the Ozeki SMS Gateway send an alert to the patient's next of kin and cardiologist. The obtained values could be substituted in Rudenko et al. 2012's equations to assist the cardiologist in his decision-making.

6. Conclusion and future work

Chronic diseases have been adjudged as a costly part of current healthcare delivery system as nearly three-quarters of medical expenditures have been recorded to have taken place on a small number of chronic illnesses, including cardiovascular disease, cancer, diabetes, and asthma. Heart failure is the cause of a high rate of readmission and it ultimately leads to death if not properly managed and supervised, thereby making cardiovascular disease remain one of the main problems in contemporary health care worldwide, accounting for approximately one third of the world's total death. The growing incidence of diabetes mellitus and the continuing epidemic of cardiovascular disease associated with this ailment have induced numerous investigators to seek evidence of pre-clinical disease besides trying to diagnose advanced stages of disease. Using a novel smartphone adapter, patients are now able to capture and transmit single-lead ECG data to their healthcare providers. Consequently, remote patient monitoring has increasingly become an attractive solution for the management of CVD. This paper, through mobile computing technologies, has succeeded in achieving acquisition of biological signals (heartbeat) and make them available wirelessly over Bluetooth. This allows an individual patient's direct involvement to closely monitor changes in her or his vital signs and provide feedback to help maintain an optimal health status. Patients and care providers can both benefit from remote monitoring as it helps patients be more engaged in their health through self-reported outcomes and provides support for cost-effective care. It also alerts medical personnel when life-threatening changes occur thereby ensuring proper communication between the patient and cardiologist via messaging towards reducing incidence of re-admission. An accurate assessment of BP levels and early identification and treatment of hypertension is thus essential for reducing the cardiovascular risk associated with this condition. The use of mobile systems that monitor patient symptoms and provide real-time advice on treatment and medication because they have the potential to control costs, reduce errors, and improve patients' experiences should be encouraged. The Cardiovascular Disease Management System (CVDMS), will be evaluated by its accuracy in classifying live monitored data. We will continue to explore methods to test the system's sensitivity to changing patient conditions towards the system's improvement following ubiquity of technology.

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Appendix

List of abbreviations used in this manuscript:

BP	Blood Pressure
CAD	Coronary artery disease
CBC	Complete Blood Count
CHD	Coronary Heart Disease
CHF	CONGESTIVE HEART FAILURE
CVA	Cerebrovascular accident
CVD	Cardiovascular Disease
DM	Diabetes Mellitus
HF	Heart Failure

HTML HyperText Markup Language
MDG Millennium Development Goal
MI Myocardial infarction
MySQL Microsoft Structured Query Language
NCD Non-Communicable Disease
NYHA New York Heart Association
PHP Hypertext Processor Processing Language
PWV Pulse Wave Velocity
UML Unified Modelling Language
WHO World Health Organization

Acknowledgment

Dr. Eloho Edosio (a cardiologist, University of Lagos Teaching Hospital (LUTH), Lagos, Lagos State),
Dr. Godwin Adebose Olawale (Physician, Public & Reproductive Health, Ministry of Health, Akure, Ondo State),
Dr. Michael Adeboro Alabi (Physician, St. Michael Medical Centre, Akure, Ondo State),
Dr. Funsho Oladipo (Physician, RJolad Hospital Nig. Ltd, Bariga, Lagos), Dr. Toogun (Physician),
Engineer Reuben Olanipekun Aladetoyinbo (Director, Ministry of Agriculture, Akure, Ondo State - posthumously);
Professor Adetokunbo Babatunde Sofoluwe (Professor of Computer Sciences & Vice-Chancellor, University of Lagos, Lagos - posthumously); ***Professor Charles Onuwa Uwadia*** (Professor of Computer Sciences, University of Lagos, Lagos);
Professor Louis Osayenum Egwari (Professor of Biological and Medical Sciences Research, Covenant University, Ota, Ogun State);
Professor Victor W. Mbarika (Professor of Management Information Sciences & Healthcare Informatics Research, Southern University and A&M College, Baton Rouge, Louisiana, USA);
Chief Pius Oluwole Akinyelure (Idanre, Ondo State);
Dr. (Mrs) Mary Adeyanju (Registered Nurse, Diabetes / HIV Educator, and Director of Nursing Services Department, Ministry of Health, Ado-Ekiti, Ekiti State),
Mrs Chikaodili Amalachi Ukegbu (Pharmacist, The Federal Polytechnic Medical Centre, Ado-Ekiti, Ekiti State),
Miss Oluwayemisi 'Tosin Oluwasusi (Registered Nurse, Government State Hospital, Ado-Ekiti, Ekiti State),
Abiola Owoniyi, Mr. and Mrs. Abiodun, Global Health Workforce Alliance (GHWA), and Canadian Coalition for Global Health Research (CCGHR).