Smart Dialysis Monitoring system

N Vedanjali, Pappula Rajasri, Mahima Rajesh, Anishma, and Kanimozhi.G
School of Electrical Engineering, VIT Chennai, Tamil Nadu, India.

Abstract: A cost-effective healthcare monitoring system equipped with a set of medical sensors to measure the body temperature, blood pressure and pulse rate of a hemodialysis patient is the need of the hour. This real time healthcare monitoring system is portable and designed in a way such that the changes in blood pressure, pulse and temperature of the patient undergoing dialysis can be monitored by doctors or nurses using their smartphones. The monitoring system sends the reading of the above-mentioned parameters to the medical staff through smartphones with the support of Bluetooth modules. The data of the respective patient can then be viewed using an android app. Thus, this healthcare monitoring system would be of great use during the process of hemodialysis as it ensures the temperature, blood pressure and pulse rate of the patient do not fall below or cross the designated values. These kinds of monitoring systems are beneficial for both doctors and patients as it gives improved quality of medical attention given to the patient, 24x7 assurance and an overall improved support and feedback to the medical team. As a result, it improves the quality of the treatment.

***Key Words**: Dialysis, temperature, pulse rate, monitoring system, sensors, Arduino uno, blood pressure, Bluetooth module*

1. INTRODUCTION

Chronic kidney disease (CKD) is one of the major public health problems worldwide. It is characterized by progressive loss in kidney function that gradually causes end-stage renal disease (ESRD), which requires kidney transplantation or dialysis [1].The main functions of kidneys is to remove excess urine and waste from the body. But at times the kidneys fail to function normally due to other health problems that have resulted in permanent damage of kidneys over time. As damage to the kidneys continues to worsen, it would lead to a chronic kidney disease, the last stage of which is known as kidney failure or end-stage renal disease [ESRD] [2]. Diabetes and high blood pressure are some of the most common causes of kidney failure. Other causes include autoimmune diseases such as lupus and IgA nephropathy, genetic diseases such as polycystic kidney disease and urinary tract problems [3].

Dialysis and kidney transplant are the major treatments for kidney failure. Dialysis is defined as the process of removing excess water, solutes, and toxins from the blood in people whose kidneys can no longer perform these functions naturally. It is also referred to as renal replacement therapy. There are 3 different types of dialysis: Hemodialysis, Peritoneal dialysis and Continuous Renal Replacement Therapy [CRRT].

Hemodialysis is the process in which a dialysis machine and a special filter called an artificial kidney, or a dialyzer, is used to clean the blood. Blood from the body is transferred to the dialyzer through the blood vessels with the help of a minor surgery [4]. A pump in the hemodialysis machine slowly draws out the blood, and sends it through another machine called a dialyzer. This works like a kidney and filters out extra salt, waste, and fluid. The cleaned blood is then sent back into the body through a second needle in the arm. This is depicted in Fig.1. Hemodialysis needs to be done about 3 times a week, each of 4 hours duration.

The three ways of performing the surgery are as follows: a) One of the veins is reconnected to an artery, allowing greater blood flow through the vein. As the vein is taken from the body of the patient it often lasts longer and may have fewer problems than the other two types... b) Graft: An artificial tube is inserted just under the skin and is connected at one end to an artery and the other end to a vein. Sometimes this access requires more maintenance and does include an increased risk of clotting. c) Catheter (central venous catheter): Sometimes used for temporary access, this is a long, two-sided tube inserted through the skin and into a vein [5].

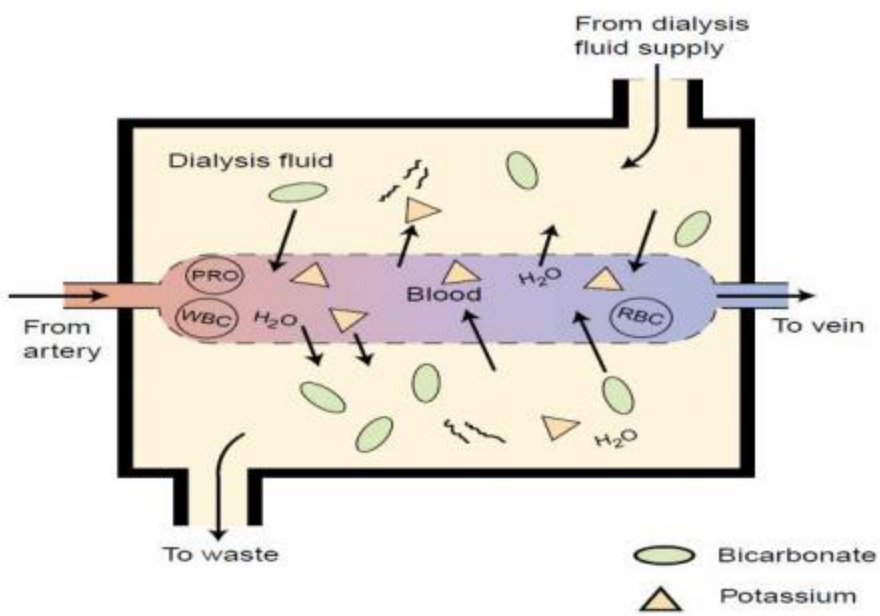

Figure 1: Schematic diagram of a hemodialysis system.

The blood compartment and dialysis solution compartment are separated by a cellophane membrane. This membrane is porous enough to allow all the constituents, except the plasma proteins and blood cells, to diffuse between the two compartments. [5]

Peritoneal dialysis uses the same principles of diffusion, osmosis, and ultrafiltration that apply to hemodialysis. The thin serous membrane of the peritoneal cavity serves as the dialyzing membrane. A silastic catheter is surgically implanted in the peritoneal cavity below the umbilicus to provide access. The catheter is tunneled through subcutaneous tissue and exits on the side of the abdomen. The dialysis process involves instilling a sterile dialyzing solution through the catheter during a period of approximately 10 minutes. The solution then can remain, or dwell, in the peritoneal cavity for a prescribed amount of time, during which the metabolic end products and extracellular fluid diffuse into the dialysis solution. At the end of the dwell time, the dialysis fluid is drained out of the peritoneal cavity by gravity into a sterile bag. Glucose in the dialysis solution accounts for water removal. Commercial dialysis solution is available in 1.5%, 2.5%, and 4.25% dextrose concentrations. Solutions with higher dextrose levels increase osmosis, causing more fluid to be removed. The most common method is continuous ambulatory peritoneal dialysis (CAPD), a self-care procedure in which the person manages the dialysis procedure and the type of solution (i.e., dextrose concentration) used at home [5]. Schematic representation of peritoneal dialysis is shown in Figure 2.

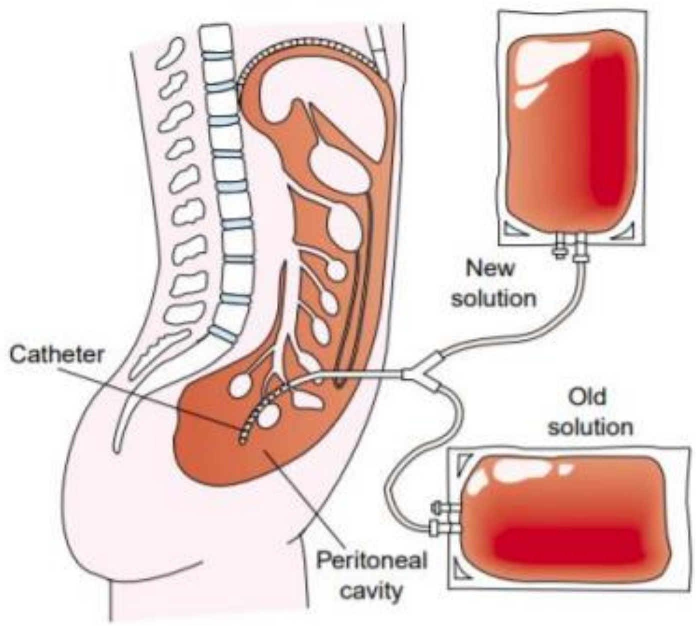

Figure 2: Schematic Diagram of peritoneal dialysis [5].

CRRT is a continuous method of blood purification that theoretically provides slow uninterrupted clearance of retained endogenous and exogenous toxins, along with providing acid-base, electrolyte, and volume homeostasis. While CRRT is intended to function 24 h a day (analogous to a native kidney), it is often interrupted [6].

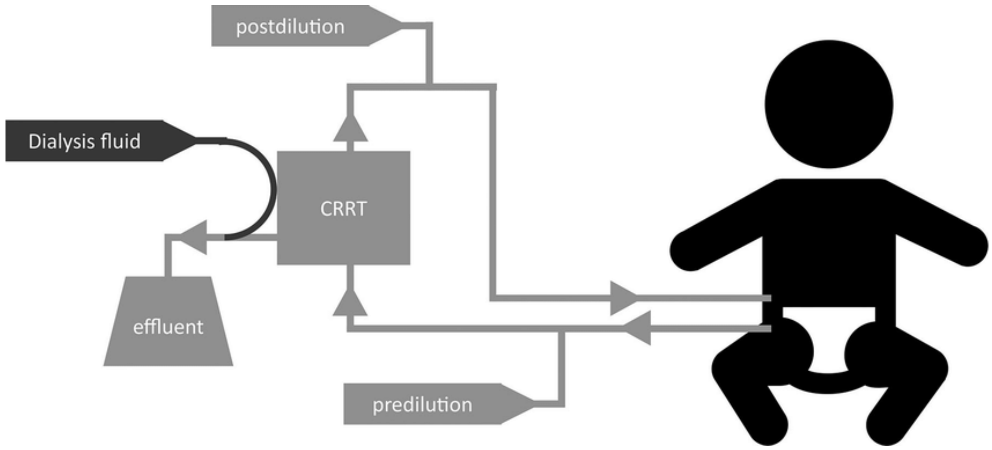

Figure 3: Schematic representation of continuous venovenous hemodiafiltration or continuous venovenous hemofiltration setup [7].

This research paper focuses mainly on a cost-effective healthcare monitoring system that will be of use during hemodialysis.

2. HEMODIALYSIS:

End stage renal disease (ESRD) is a worldwide public health problem [8]. ESRD has become a concern increasing the number of patients maintained on hemodialysis prior to renal transplantation [9]. Time needed for your dialysis depends on how well your kidneys work, how much fluid weight you gain between treatments, normally hemodialysis treatment lasts about 4 hours and is done 3 times a week [9]. Newly when dialysis was introduced most of the people with age >= 80 used to undergo this treatment but now in this new era of living age > 65 are started undergoing this treatment [10]. Early versus late dialysis therapy initiation; more frequent (>3 times a week) or longer duration (>4.5 hours) compared to conventional hemodialysis; low- versus high-flux dialyzer membranes [11]. Temperature of the body, dialysate temperature and room temperature play a major role in the dialysis room [12]. Lowering the temperature from 37 degrees C to 34-35.5 degrees C has improved the cardiovascular stability of many hemodialysis patients [12]. The Kidney Disease Outcomes Quality Initiative (KDOQI) guidelines from 2005 recommended a pre dialysis BP target of < 140/90mm Hg and post dialysis BP target of < 130/80 mm Hg (Table 1) [13]. –The most common side effect of hemodialysis is low blood pressure. It can occur when too much fluid is removed from the blood during hemodialysis, this causes pressure to drop [14].

Table 1: Blood pressure targets according to major clinical practice guidelines.

GUIDELINES	BLOOD PRESSURE TARGET
KDOQI 2005 Guidelines	Pre dialysis BP < 140/90mm Hg Post dialysis BP < 130/80mm Hg
KDOQI 2015 Guidelines Update	No target defined, citing paucity of clinical trial data
Canadian Society of Nephrology 2006 guidelines	Pre dialysis BP < 140/90 mm Hg
European ERA – EDTA 2017 Guidelines	No target defined, citing paucity of clinical trial data
Japanese society for Dialysis therapy 2012 guidelines	Pre dialysis BP < 140/90 mm Hg

A normal resting heart rate should be 60-100 beats per minute. The kidneys also are responsible for maintaining a steady volume of blood in your body, removing excess fluid by way of urination. If your kidney function is impaired, your blood volume increases, that increased stress on your heart causes it to stretch and also trigger this abnormal heart rhythm [15]. In the (Table 2) for men the pre-HD Systolic BP is 153.4 mm Hg as mentioned and the Diastolic BP is 78.8 mm Hg. The pulse rate taken before the HD was 74.6 beats per minute [16].

Table 2: Pre-HD Blood pressure and pulse rate in men.

For Men	
Pre-HD Systolic BP, mm Hg	153.4
Pre-HD Diastolic BP, mm Hg	78.8
Pre-HD pulse rate, bpm	74.6

Now the blood pressure is compared to the pulse rate relatively as mentioned in the (Table3). When the person is having pulse rate between 40 to 69 beats per minute then the blood pressure of the person is noted as 151.3/75.8 mm Hg and when the pulse rate is between 70 to 129 beats per minute then the blood pressure is 154.5/80.2 mm Hg which is measure before the process of taking dialysis [16].

Table 3: Comparing on Blood pressure and pulse rate variations.

	Pulse rate 40-69 bpm	Pulse rate 70-129 bpm
Pre-HD Systolic BP, mm Hg	151.3	154.5
Pre-HD Diastolic BP, mm Hg	75.8	80.2

3. BLOCK DIAGRAM OF PROPOSED MODEL

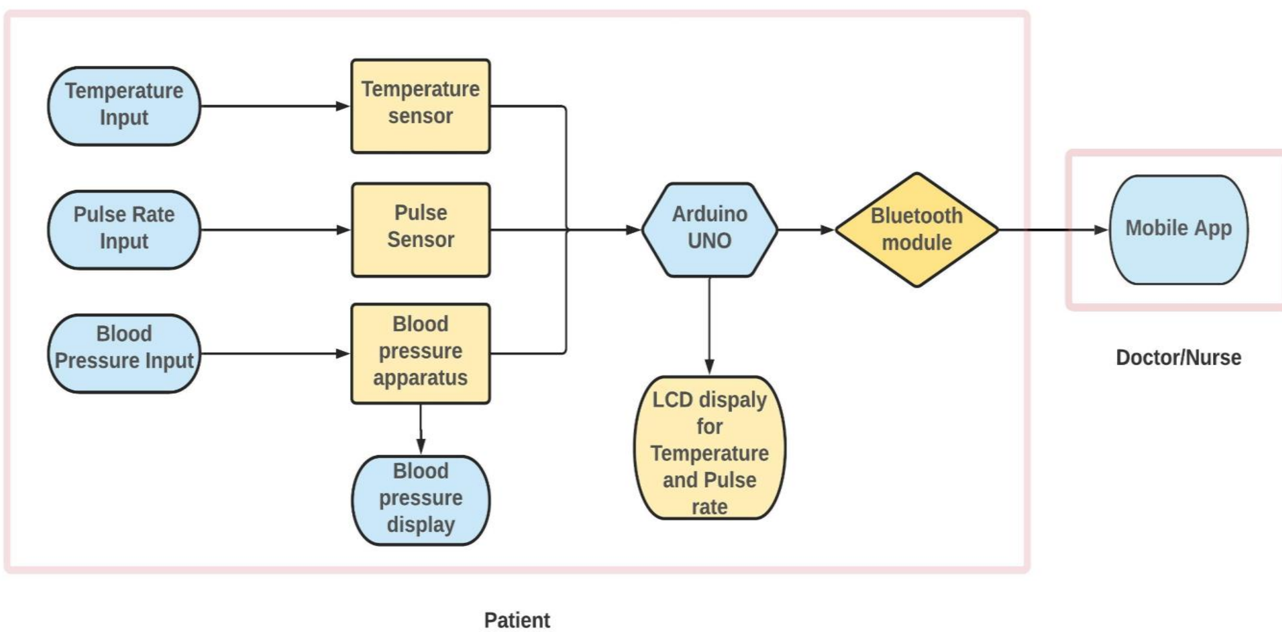

Figure 4 Block Diagram of electronic temperature, blood pressure and pulse rate monitoring machine during dialysis.

The block diagram of the proposed model is shown in Fig.6.

1.Sensors

2.Arduino

3.Bluetooth module

4.Mobile Application

As shown in figure 4 in the block diagram, give the inputs of temperature, pulse rate and blood pressure. These readings are read by the temperature sensor, pulse rate sensor and blood pressure apparatus respectively. This information is sent to Arduino and gives the display of temperature and pulse rate reading in LCD display and blood pressure readings in the BP display. The Bluetooth module is also connected to the Arduino which sends the information of reading to the Mobile app which is used by a doctor or nurse.

Proposed Model:

Blood Pressure: An I2C EEPROM is connected to the ASIC of the Blood pressure monitoring device. The ASIC acts as the master and the I2C EEPROM acts as the slave. The master transfers to the slave through the I2C bus. Further the data is bypassed by 11 connecting the Arduino Uno as a slave on I2C bus. Hence, the Arduino is also able to read the data when the data is sent from the ASIC to the I2C.

The pin 14 VCC of EEPROM is connected to 3.3V. The pin 7 of I2C EEPROM is grounded. Pin 9, 10 SCL, SDC of EEPROM is connected to the A5, A4 pins in the Arduino Uno board. The valve of the BP machine is connected to the digital pin 3 in the Arduino. A switch is also connected to the Arduino Uno which helps to start the blood pressure measurement.

Temperature Sensor: This unit consists of a temperature sensor to measure the temperature of a patient which is connected directly to the microcontroller. The temperature sensor used in this project is LM35, which is an analog sensor. The microcontroller receives the data in analog form and converts it into digital form then sends it to the RF transmitter so that the data can be sent to the remote end. At the receiving end, RF receiver receives the data and sends it to the microcontroller. The microcontroller does the processing and finally the data is displayed on the LCD along with the data of heartbeat. The scaling factor for LM35 is 0.01V/°C.

Body temperature is measured by holding LM35 with the patient's finger and corresponding change in temperature is converted into analog voltage which is then fed to the microcontroller by the middle pin of LM35. The microcontroller has ADC in it and it does further processing and sends the measured data to the remote end via RF transmitter. At the remote end, the RF receiver receives the data and sends it to the microcontroller which then processes and displays the data in the LCD.

Pulse sensor:

The amount of light that was detected by the phototransistor varied with the patient’s heart pulse, as the amount of absorbed IR light changed with the flow of blood, which is directly linked to the heart rate. This signal was then amplified, filtered, and sent to the microcontroller to be analyzed. The heart rate sensor was mounted in the finger ring as this position proved to give the best response. The sensor after filtering provides a clean wave that when observed on an oscilloscope confirms that the sensor was correctly measuring the patient's pulse.

To get accurate results with the heart rate sensor, measure the pulse at the fingertip like commercial devices. The signal (analog) originally was too small to detect, and without amplification proved to be too noisy to extract the heart rate. Because of this, operational amplifiers were used to extract the heart rate signal. After amplifying, the signal was fed to the comparator, resulting in output in the form of pulses. The signal in the form of pulses is interfaced with a microcontroller through its digital port for further processing. The heart rate is measured by using the hardware interrupt facility of the microcontroller.

Android app:

This mobile application is connected with the Bluetooth HC-05 and the readings received via Bluetooth are displayed on the screen. The doctor /medical staff can easily connect the app with the Bluetooth module with just a click. Moreover, the patient’s medical history can be stored in the app which makes it easy for the doctor to review the patient's condition. In Case of an emergency a call is automatically made to the doctor through the app.

4. HARDWARE SETUP:

Table 4: Hardware Components

Component Name	Specification
EEPROM	I2C
Blood pressure sensor	BPM180
Arduino uno	R3CH340G ATmega328p
Temperature sensor	LM35
Pulse sensor	SEN-11574
LCD display	JHD 126A
Bluetooth module	HC-05
Handcuff, breadboard, jumper wires	-

Flow chart:

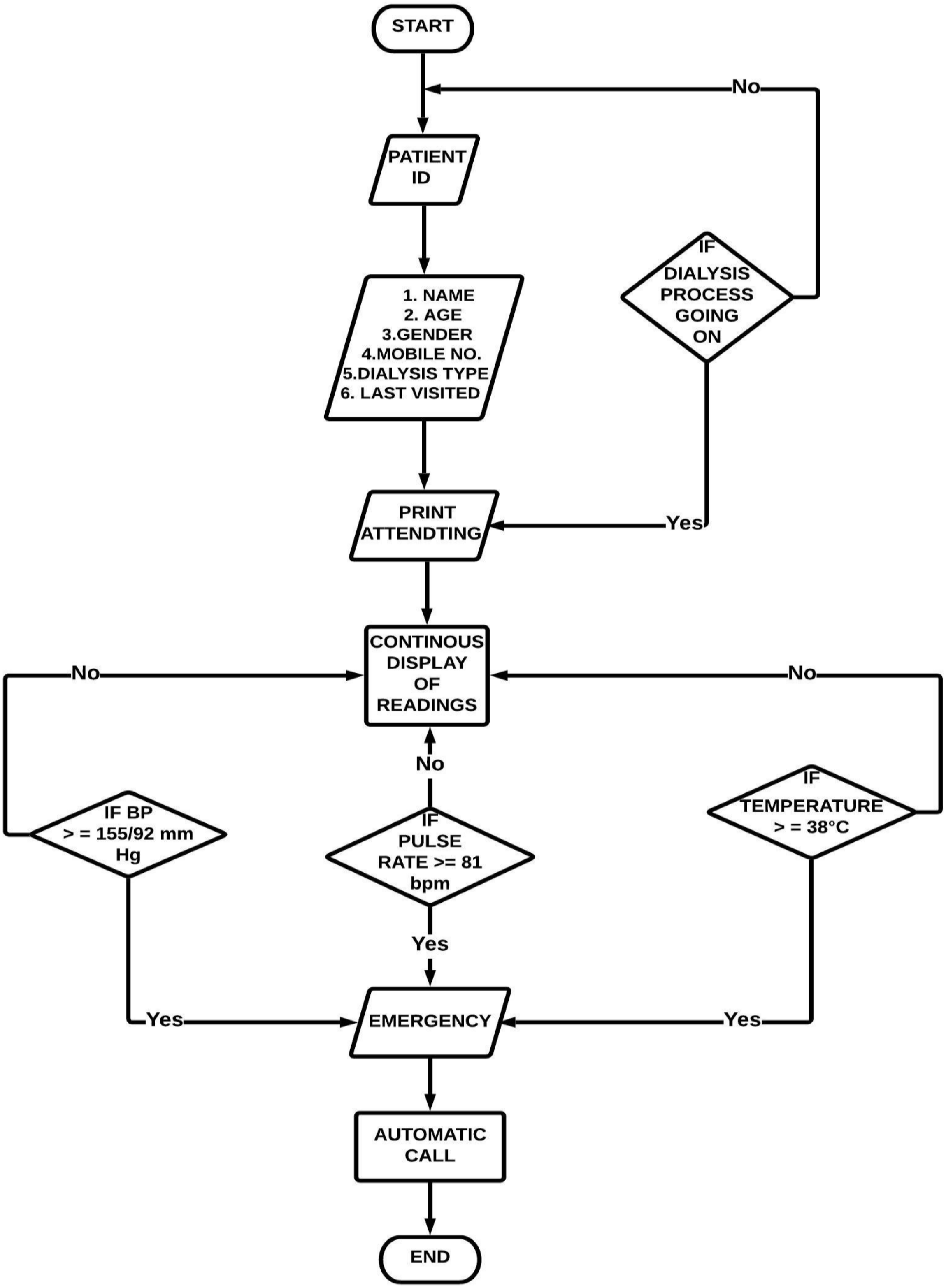

Figure 5: Flow diagram of the smart dialysis app.

As mentioned in the figure 5, the patient ID is to be entered and then the saved history name, age, gender, mobile number, type of dialysis and last visit of the patient to the doctor along with the on-going status of the patient will be displayed on the screen. The present status menu indicates whether the dialysis is being done or not. If the dialysis machine is on, the on-going status shows "attending". The doctor can click on the next button to observe the readings continuously. If the temperature is greater than or equal to 38°C or the blood pressure is greater than or equal to 155/92 mm Hg or pulse rate is greater than or equal to 81 beats per minute (bpm) an alert message will be displayed on the mobile screen. During an emergency, a phone call will be made to the doctor immediately.

5.MOBILE APPLICATION:

Case-1:

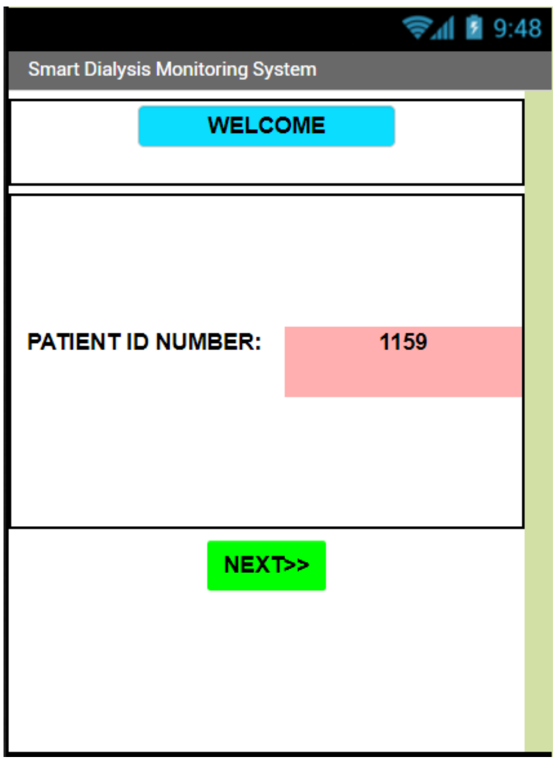

Figure 6a: Welcome Page

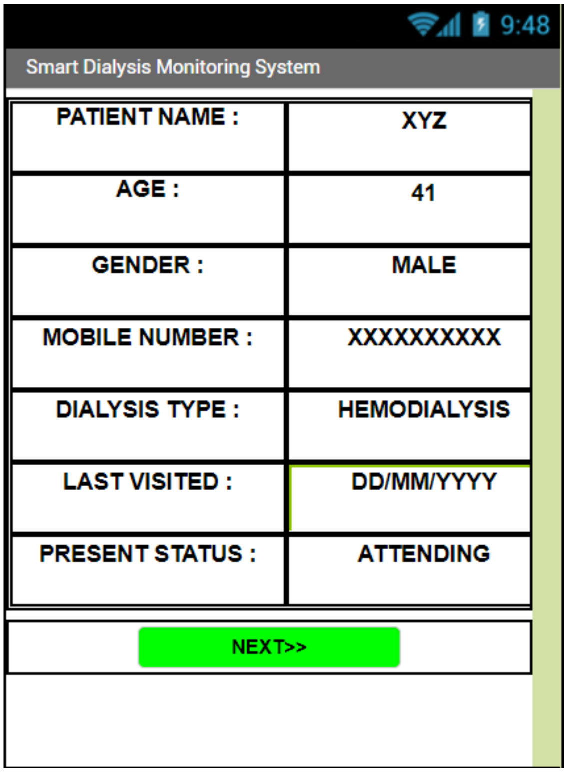

Figure 6b: Patient details.

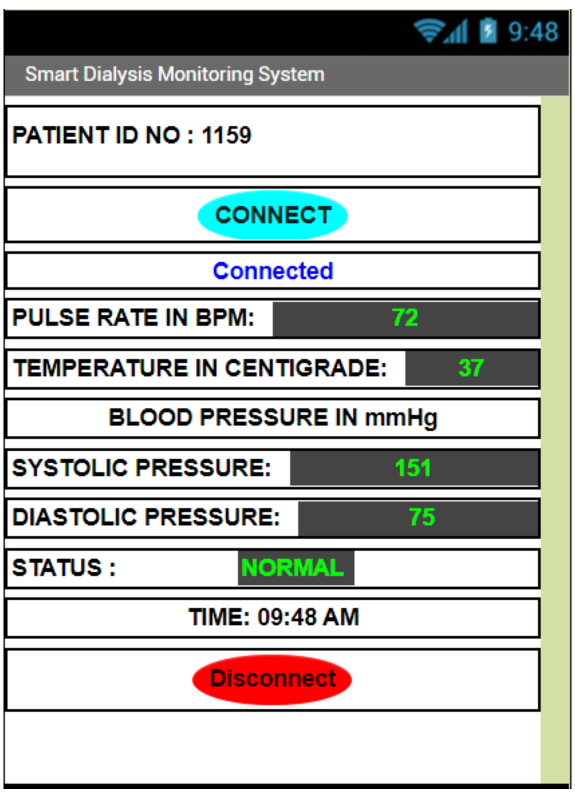

Figure 6c: Readings during dialysis

Case-2:

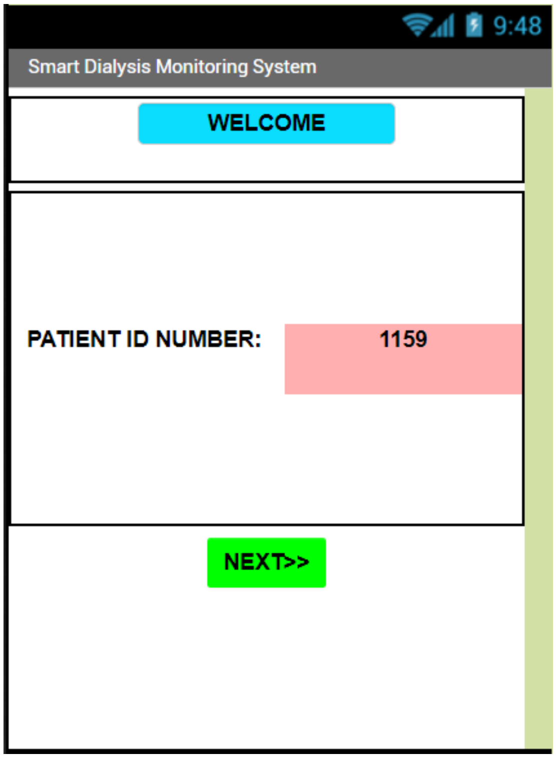

Figure 7a: Welcome page

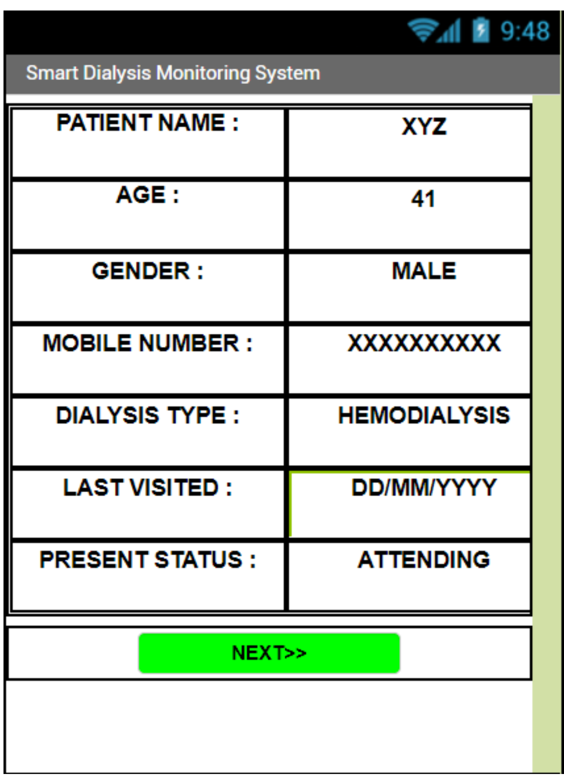

Figure 7b: Patient details

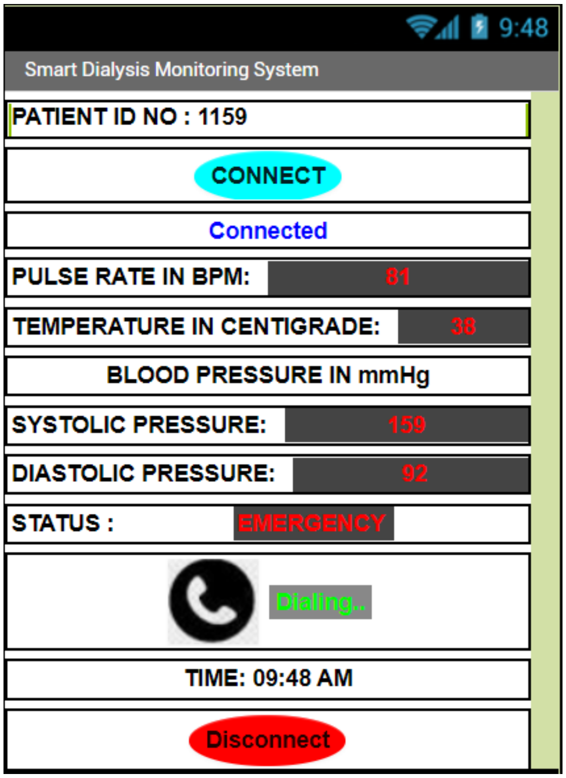

Figure 7c: Readings during dialysis

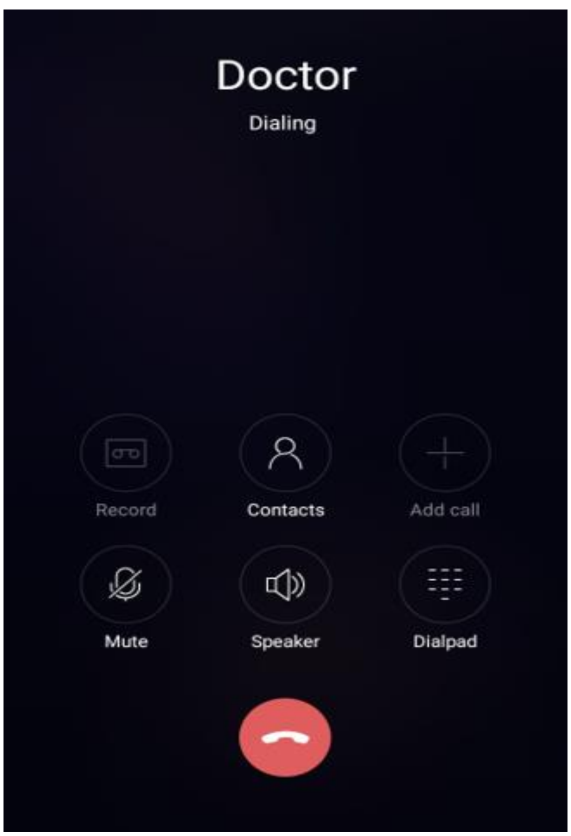

Figure 7d: Phone call to doctor/nurse

As depicted in figure 6a the patient id number is to be entered in the welcome page of the mobile application and the saved patient details would be displayed on clicking on the “next” button as shown in figure 6b. Upon clicking on the “next” button and by connecting to the Bluetooth device, a continuous monitoring of pulse rate, body temperature, blood pressure along with time and status of the patient is displayed as shown in the figure 6c.

If all the readings are in normal range as mentioned in table2 and table3, the status of the person is specified as normal and the readings are displayed in green colour as shown in figure 6c. If any of the readings exceeds the normal range, then the readings are displayed in red colour as shown in figure 7c and the patient is considered to be in a state of emergency. In the case of an emergency, the doctor\nurse is called immediately.

6. HARDWARE RESULTS:

1.Circuit:

Figure 8a: Experimental setup - Top view

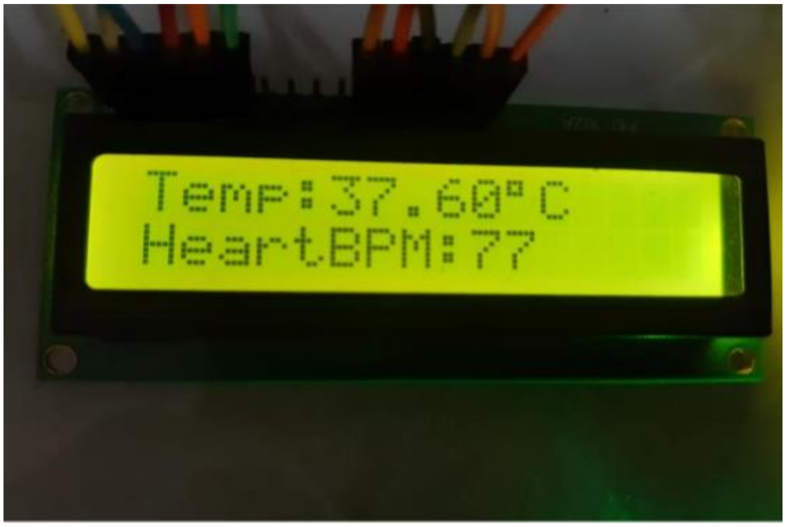

Figure 8b: Temperature and pulse rate readings on LCD display

Figure 8c: Blood pressure readings on LCD display

Pulse sensor, blood pressure sensor, temperature sensor, Arduino and Bluetooth module are connected as a circuit with the help of connecting wires and breadboard. When the device gets successfully paired with the sensor of Bluetooth module, the LED lights on Bluetooth sensor will start blinking at a slower rate than usual. After successful connection, ‘connected’ message will be displayed on the main screen of the mobile application. Then android app will start to display the data received from the transmitter side as shown in figure 8a. The temperature, pulse rate readings are displayed in LCD as shown in figure 8b and blood pressure readings are displayed in BP apparatus display as shown in figure 8c

7.CONCLUSION:

A cost-effective healthcare monitoring system is used during hemodialysis has been developed successfully and working of the device has also been verified. This healthcare monitoring system offers very good medical assistance with integrated IOT to improve efficiency of the system. This not only saves time but also improves the quality of service as doctors would be notified in case of any medical emergency through the mobile app.

REFERENCES:

1. Mousa, I., Ataba, R., Al-ali, K. et al. **Dialysis-related factors affecting self-efficacy and quality of life in patients on haemodialysis: a cross-sectional study from Palestine.** Ren Replace Ther 4, 21 (2018). https://doi.org/10.1186/s41100-018-0162-y
2. Z. Bi et al., **"A Practical Electronic Health Record-Based Dry Weight Supervision Model for Hemodialysis Patients,"** in IEEE Journal of Translational Engineering in Health and Medicine, vol. 7, pp. 1-9, 2019, Art no. 4200109, doi: 10.1109/JTEHM.2019.2948604.https://ieeexplore.ieee.org/document/8882347
3. **End Stage Renal Disease Briefing Book For State And PolicymakersAuthors :** Kristin M. Larson, MSN, RN, ANP, Health Policy Committee Chairperson Mary Houglum, RN, Kidney Disease Awareness and Education Week Advisor Billie Axley, BSN, RN, CNN, Kidney Disease Awareness and Education Week Advisor Lesley Dinwiddie, MSN, RN, FNP, CNN, Nephrology Nurse Week Advisor Kathleen Smith, BS, RN, CNN, ANNA State Health Policy Consultant James W. Twaddell, ANNA Health Policy Consultant Updated by the 2009-2010 Health Policy Committee June 2009.
4. **Handbook of Dialysis** Edited by John T. Daugirdas, MD, FACP, FASN Clinical Professor of Medicine University of Illinois at Chicago Chicago, Illinois Peter G. Blake, MB, FRCPC, FRCPI Professor of Medicine Western University London, Ontario, Canada
5. Paul, A. & Girish, Chiruthanur & Shilpa, T. & Manogna, Katta & Susmitha, A.. (2017). **Renal Vascularisation Causing End - Stage Failures and Outcomes: A Pooled Analysis of Community Based Studies.** International Journal of Pharmaceutical Sciences and Drug Research. 9. 10.25004/IJPSDR.2017.090510.
6. Rewa, O., Villeneuve, PM., Eurich, D.T. et al. **Quality indicators in continuous renal replacement therapy (CRRT) care in critically ill patients: protocol for a systematic review.** Syst Rev 4, 102 (2015). https://doi.org/10.1186/s13643-015-0088-1
7. Jonckheer, Joop & Vergaelen, Klaar & Spapen, Herbert & Malbrain, Manu & De Waele, Elisabeth. (2018). **Modification of Nutrition Therapy During Continuous Renal Replacement Therapy in Critically Ill Pediatric Patients: A Narrative

Review and Recommendations. Nutrition in Clinical Practice. 34. 10.1002/ncp.10231.

8. Marie Claire Mukakarangwa, Geldine Chironda, Busisiwe Bhengu, Godfrey Katende, **"Adherence to Hemodialysis and Associated Factors among End Stage Renal Disease Patients at Selected Nephrology Units in Rwanda: A Descriptive Cross-Sectional Study",** *Nursing Research and Practice*, vol. 2018, Article ID 4372716, 8 pages, 2018. https://doi.org/10.1155/2018/4372716.
9. Dad, T., Tighiouart, H., Lacson, E. *et al.* **Hemodialysis patient characteristics associated with better experience as measured by the In-center Hemodialysis Consumer Assessment of Healthcare Providers and Systems (ICH CAHPS) survey.** *BMC Nephrol* 19, 340 (2018). https://doi.org/10.1186/s12882-018-1147-3.
10. Piccoli GB, Sofronie AC, Coindre JP. **The strange case of Mr. H. Starting dialysis at 90 years of age: clinical choices impact on ethical decisions**. *BMC Med Ethics*. 2017;18(1):61. Published 2017 Nov 9. doi:10.1186/s12910-017-0219-4.
11. Slinin Y, Greer N, Ishani A, MacDonald R, Olson C, Rutks I, Wilt TJ. **Timing of dialysis initiation, duration and frequency of hemodialysis sessions, and membrane flux: a systematic review for a KDOQI clinical practice guideline.** Am J Kidney Dis. 2015 Nov;66(5):823-36. doi: 10.1053/j.ajkd.2014.11.031. PMID: 26498415.
12. Pérgola PE, Habiba NM, Johnson JM. Body temperature regulation during hemodialysis in long-term patients: is it time to change dialysate temperature prescription? Am J Kidney Dis. 2004 Jul;44(1):155-65. doi: 10.1053/j.ajkd.2004.03.036. PMID: 15211448.
13. McCallum W, Sarnak MJ. **Blood pressure target for the dialysis patient**. *Semin Dial*. 2019;32(1):35-40. doi:10.1111/sdi.12754.
14. Taniyama, Y. **Management of hypertension for patients undergoing dialysis therapy.** *Ren Replace Ther* **2,** 21 (2016). https://doi.org/10.1186/s41100-016-0034-2
15. Paungpaga Lertdumrongluk, Elani Streja, Connie M. Rhee, John J. Sim, Daniel Gillen, Csaba P. Kovesdy, Kamyar Kalantar-Zadeh **Changes in Pulse Pressure during Hemodialysis Treatment and Survival in Maintenance Dialysis Patients.** CJASN Jul 2015, 10 (7) 1179-1191; DOI: 10.2215/CJN.09000914.
16. Kunitoshi Iseki, Shigeru Nakai, Kunihiro Yamagata, Yoshiharu Tsubakihara, **Tachycardia as a predictor of poor survival in chronic haemodialysis patients,** ***Nephrology Dialysis Transplantation*****,** Volume 26, Issue 3, March 2011, Pages 963–969, https://doi.org/10.1093/ndt/gfq507