Automated Peritoneal Dialysis: A Cost-Effective Process for Better Living

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***Abstract*—Kidneys play a vital role in human excretory process and need to be taken care off. The most common method of artificial filtration when the kidney function fails is dialysis which is of two types: (a) Hemodialysis, (b) Peritoneal Dialysis. Automated Peritoneal Dialysis which is a types of Peritoneal Dialysis has become more and more popular in recent years as a substitute for hemodialysis. In this view, a low cost machine for APD, affordable to common man is proposed.**

Thus the paper is aimed to evoke a sense of awareness among the people about the option they have which is APD for a better and healthier lifestyle. The proposed cost-effective method is designed after taking into account the advantages and disadvantages of the available systems in the market.

Keywords—Kidneys; Peritoneal Dialysis; Automated Peritoneal Dialysis (APD); End Stage Renal Disease (ESRD); Continuous ambulatory peritoneal dialysis (CAPD);

I. INTRODUCTION

Automated Peritoneal Dialysis is the most widely used dialysis treatments in the hospitals for ESRD patients. It uses an automated programmed machine to efficiently perform artificial filtration. The dialysate is filled in the abdominal cavity and the diffused waste is removed from the abdominal cavity with the common working of pumps, motors and other peripherals controlled by the microcontroller.

The following section explains the role of kidneys, their functions, the acute and chronic causes of kidney failure, the treatment solution: Dialysis and its types.

(*Kidney and its Function*)

Kidneys: lie on the either side of the spinal cord in the retroperitoneal cavity and are of the size of person's fist. Kidney is a major part of the excretory system. They perform these functions of removing excess water, salts and wastes of protein metabolism from the blood while providing nutrients back to the blood. They perform this function with the help of million filtering sections called 'nephrons'. These nephrons work through a two-way process: (a) the glomerulus lets the fluid & waste products pass through it; preventing blood cells & other large molecules from passing, (b) the filtered fluid then passes through 'tubule', which resends the needed nutrients back to the bloodstream, thus removing waste(urine).

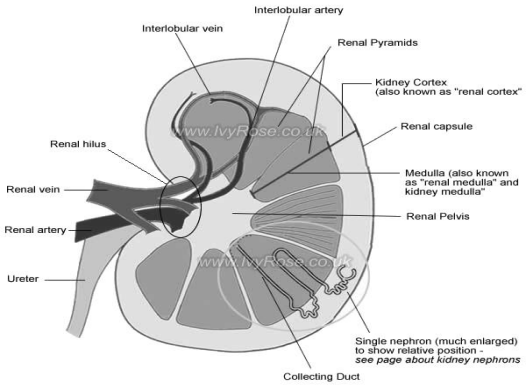

Figure (1) shows the kidney anatomy with its filtering sections 'nephrons'

Most kidney diseases attack the nephron, causing them to lose their filtering capacity.The nephrons can be damaged quickly, often as a result of an injury or due to poisoning. But most of the kidney diseases destroy the kidney slowly and silently. It is only after years and when not taken proper care, the damage becomes apparent. The common and mostly observed causes of kidney failure are diabetes and high blood pressure. People with history of the causes must take extra precautions to avoid kidney diseases.

When the waste from the body is not eliminated it means that the kidney is not functioning in ideal way and needs attention. Ignoring the issue may lead to end stage renal disease (ESRD) which is a threat to life as it affects removal of waste & restoration of body fluid volume and compositions. Therefore some filtration process is needed to remove waste and keep the blood pure. This process is widely known as 'Dialysis'.

Dialysis may offer filtration process as a replacement of kidney but it does not provide a permanent replacement of kidney function unless a kidney transplant is done by the patient. There are advantages as well as disadvantages when a patient opts for dialysis. Dialysis may or may not cause nausea, poor appetite and loss of energy, weight loss, irregular menstrual periods, anemia and many other things in a patient. Apart from the above causes of dialysis it manages to offer a healthy life to patients with ESRD.

II. DIALYSIS AND ITS TYPES

Dialysis is an artificial process of filtration which eliminates the waste & unwanted water from the human body.

Dialysis can be performed in two ways: (a) Hemodialysis, (b) Peritoneal Dialysis. In Hemodialysis, blood is sent through a filter outside human body to remove wastes and the clean blood is returned to the body. Whereas in Peritoneal Dialysis (PD), a fluid is put into the patients abdomen; this fluid captures the wastes present in the blood. After few hours, the fluid which consists of the body toxins is drained out from the abdominal cavity. This process is repeated by adding fresh bag of fluid into the abdomen at regular intervals. Both the dialysis methods work in efficient ways to replace kidney function in human body with ESRD; but the choice is mostly left to patients.

Peritoneal Dialysis is being used as an alternative for hemodialysis since decades. There are two ways in which PD can take place: (a) Continuous Ambulatory Peritoneal Dialysis (CAPD), (b) Automated Peritoneal Dialysis (APD).

A. CAPD: This process does not require a machine to complete the process. Patient needs to fill the stomach with dialysate and drain it out every 4-5 hours with gravity. This process involves several exchanges during the course of each day and hence may cause inconvinience for working people.

B. APD: This process requires a machine which performs the exchanges (instead of gravity) while the patient sleeps at night. The fluid is automatically filled in the cavity and the filtration process occurs in the abdominal cavity and then the waste fluid is drained out. The patient does not feel uncomfortable because of this process due to its very flexible nature.

APD (a type of PD) is getting popular with the upcoming developments in this field. The motivation of this research is to educate people about APD and the flexibility it can provide to a person suffering from ESRD.

The next section Literature Survey explains PD and highlights some recent research works performed & published by various researchers.

III. LITERATURE SURVEY

A. Principle of Peritoneal dialysis (Heading 2)

Peritoneal Dialysis (PD) uses a part of abdomen to complete its operation; a semipermeable membrane called 'Peritoneum' which lines the walls of the abdomen & covers the internal organs. Peritoneum membrane consists of tiny microscopic pores that allow very small particles or molecules present in the liquid to pass through the membrane to another side; thus forbidding the particles larger than the holes in the peritoneum membrane to pass through.

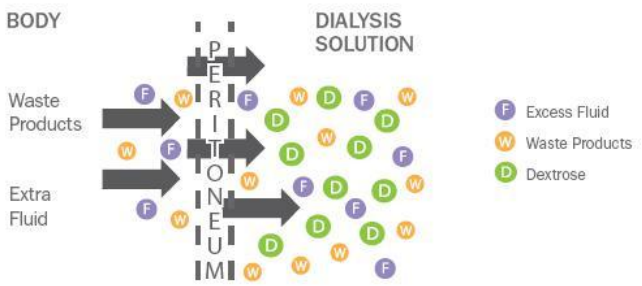

Figure (2) how the semipermeable membrane 'Peritoneum' filters the wastes from the blood during PD when dialysate is present in the abdomen cavity.

Usually this process is done manually as the gravity works to get the fluid inside and then drain it out; this type of PD is called Continuous Ambulatory Peritoneal Dialysis (CAPD). But, APD uses a properly programmed machine to perform exchanges automatically while the patient sleeps at night. The time for which the dialysate remains in the body is called as 'dwell time'. In the day time, the stomach is filled with dialysate and it remains in the body for the whole day which is the maximum dwell time.

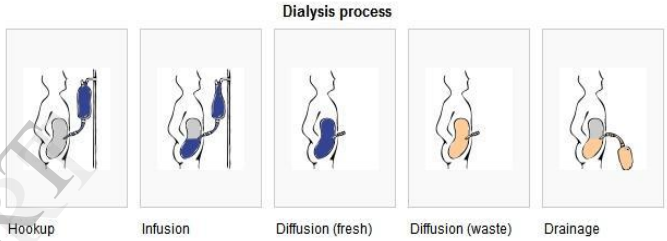

Figure (3) below shows the process of Dialysis

The five steps are: (a) Hookup- the patient attaches its catheter to the dialysate fluid, (b) Infusion- the fresh fluid is filled in the abdomen cavity, (c) Diffusion (fresh)- The fluid remains in the abdomen for a period of time 'dwell time' for the processes osmosis & diffusion, (d) Diffusion (waste)- after the filtration is complete the waste is collected in the cavity, (e) Drainage- waste from the filtration collected in the abdomen cavity is drained out of the body. And again fresh amount of dialysate is filled in the abdomen cavity.

B. Reviews

In the 'Textbook of Medical Physiology' by Guyton & Hall, Unit V, Chapter 26, 27, the authors have thoroughly explained the human physiology of Body Fluids & Kidneys. The various topics covered are- (a) anatomy of kidney, (b) glomerular filtration, (c) renal blood flow & its control, (d) tubular processing, etc. All these topics highlight the Urine formation in human body and it is controlled by kidneys.

Nephrology Dialysis Transplantation (NDT) in one of its published journal titled "Automated vs Continuous Ambulatory Peritoneal Dialysis (CAPD): A systematic review of randomized controlled trials" by many authors explained how the study was performed and results were analyzed for both types of PD methods. In their review results, they concluded that APD has been reported to have several advantages over CAPD with lower

peritonitis. The results were based on randomized controlled trails (RCTs).

In a research work published in 2012 by Praveen Tengse, Shrujan Kumar D N and Vidya M J of R V College of Engineering, Bangalore, India in IJARCCE titled "Portable Kidney Machines", the students described the general operations performed by a dialysis machine. Their research included comparison of various dialysis machines available and how the machine work. They analyzed a Portable Dialysis Machine of Maxim which is designed for patients to perform dialysis at home. They observed that patients have to visit hospitals 3 – 4 times every week to perform dialysis; which is not that flexible for working people. But after analyzing the mechanism of the Maxim Model, they concluded that with home machines, patients have more flexibility in scheduling dialysis and also that they can dialyze for longer periods and frequently.

The article titled "In Younger Dialysis Patients, APD is associated with better long-term patient and technique survival than is CAPD" published by Division of Nephrology, Taiwan concluded that APD patients have better and long-term technique survival.

US 843880 B2 Patent highlighted the disadvantage in the current APD machines; it stated that the APD systems must be improved for home use. But one disadvantage with the APD systems is that they are vulnerable to electric shock due to 'leakage current'. The leakage current may cause electric shock because the catheter connects the human abdomen and the machine directly.

IV. EXISTING SYSTEMS FOR DIALYSIS

The existing systems in the market for dialysis are mostly manufactured by Baxter International, an American health care company which focuses on products to treat kidney disease, hemophilia and acute and chronic medical conditions. Baxter Home Choice Automated PD system like many other electric equipment's, plugs into an electric socket. There is a guide book provided to understand the operation of the machine by patients. A patient can have 4 to 5 bags of dialysate attached to the machine for the exchanges.

Proper training is provided to the patients using these machine. Also a user manual is delivered incase if the user faces any problem with the machine. These systems have proved very efficient for the patients who have opted for it.

One major disadvantage of these systems is they are extremely expensive for common man who cannot afford buying such costly systems. Also it becomes difficult to visit hospital 3-4 times a week for dialysis exchanges.

The cases with ESRD is increasing day by day, therefore it is necessary to encourage patients to go for APDs to have a flexible life. For that, there has to come tradeoff between cost (especially NRE cost) and the selling price without hampering the accurate function of the dialysis machine. The cost of the machine can be lessened for the use of people who cannot afford home treatment.

Also, as mentioned in the Literature Review, a patent has highlighted the disadvantage in the current APD systems which is due to the presence of leakage current. This disadvantage can be eliminated by the addition of an additional circuitry for leakage current protection.

V. PROPOSED MODEL

In the above section, the researcher discussed the existing model by Baxter International, which is a very popular system in the market; but with the major disadvantage of cost.

[8] In the reference, the author Peter G. Blake has mentioned the one disadvantage of APD over CAPD is its higher cost. The expense consists of the capital cost of the cycler used in the filtration, plus the extra daily cost of additional dialysis solutions and tubing that is required in APD. The author also mentions that there are insufficient data for any sort of accurate cost-benefit analysis at that time, and issues in the programs had to be resolved.

Hence, to combat with the above disadvantages, researcher proposes a model for Automated Peritoneal Dialysis (APD) which is a cost effective system; can be efficiently used by any patient who chooses home automation. This model provides a user friendly approach to the dialysis process. The researcher has finalized the block diagram after the literature and market survey, the further part of the design is to be done later. The machine is PIC based circuitry due to which, it offers flexibility in programming.

Once the prescription of the patient is fed in the machine, he/she does not have to change the settings until the next prescription arrives. The patient just have to connect the catheter to the machine and the machine will perform its operation in the given period of time.

A. Block Diagram of APD machine

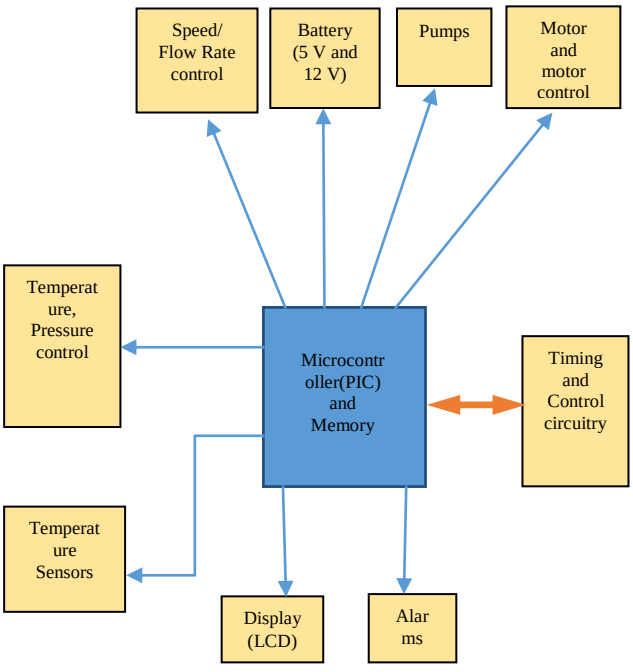

Figure (4): Block Diagram of the Proposed Model

The block diagram in the figure (4) consists of a PIC based circuitry and its peripherals as listed and explained below:

i. Temperature & Pressure Control: the dialysate which is filled in the abdomen cavity of the patient is to be heated at a temperature of 37 to 40 degrees. This is to be controlled accurately as per the body temperature of the patient.
ii. Flow Rate Control: the rate at which the fluid is filled in the cavity should be uniform. A timing circuit can also be used to control the flow of dialysate in the body.
iii. Pumps: two pumps are required in the machine; one for pumping the dialysate from the bag into the cavity and another from pumping out the waste from the cavity after diffusion of waste takes place. The function of pumps are controlled by PIC with the help of Motors (Solenoid Valves)
iv. Motors and Motor Control: motors control the entire operations from flow control to pumping operations. Solenoid Valves are open-close circuits; when the dialysate is to be filled in the cavity, the motor opens the valve and then the pump pumps the dialysate from the solution bag into the abdominal cavity; after that the valve is closed by the PIC by sending a pulse.
v. Timing Circuitry: the timing circuit monitors all the operation since the machine is turned on till it shuts off. It also gives alarms when the machine is On, Off or any error is detected during the process.
vi. Patient Monitoring Unit: blood pressure and the temperature of the patient is observed in this unit. If in some critical case, the blood pressure of the patient increases, the PIC and the timing circuitry triggers the alarm.
vii. Microcontroller PIC: PIC is a very flexible microcontroller. Its features include- (a) ideal for motor control, (b) in-built 10 bit ADC and other features like low power consumption, good interface for communication buses (CAN, LIN, SPI, etc.), simplified for programming with hardware and software.

These are the features of the proposed design, a separate memory unit is to be added to save the results of the dialysis, which can be helpful to analyze the condition of the patient in the future. Another advantage of the machine is that it compares the amount of solution inserted in the abdomen cavity and the amount of storage drained and display the net difference between the two volumes. This can help the doctor to know how efficiently the patient is responding to the treatment.

B. Ideal Working of the Circuit

Initially the patient needs to connect the catheter from the body to the solution bag and then turn on the machine.
The working of the circuit can be summarized as:

i. The machine or circuit when connected to a switch, the switch will trigger the power supply on the board which in turn will turn on the PIC. The PIC issues a pulse to the timing circuit and gives an alarm indicating that the machine is ON.
ii. Patient Monitoring unit takes the initial reading of the patient. The valve is closed for this time.
iii. The heated dialysate (37-40 degree) is then pumped into the abdomen cavity when the PIC sends a pulse to Solenoid Valve; which opens(open circuit) and the motor follows the pumping of the dialysate in the abdominal cavity.
iv. As soon as the required amount of solution is filled, the PIC issues another pulse to the valve which closes the valve.
v. The fluid remains in the cavity for a certain amount of time called the 'dwell time': during the dwell time diffusion of waste takes place (as explained in the previous sections). This time fixed for a patient but it can vary for children, adults and senior citizens depending upon their capability of exchanges.
vi. After the dwell time, Solenoid valve is again open circuit and the motor pumps out the waste fluid from the abdomen cavity.
vii. Fresh fluid is again filled in the cavity for the next exchange. This continues 4-5 times every night for 8-9 hours.

The machine won't make any noise while the process is on unless an error arises. This gives a patient a healthy and sound sleep. The proposed circuit works in this fashion to encourage people and give them motivation for life.

VI. CONCLUSION

The survey results and published articles point out the need for making people aware about the need for a flexible dialysis treatment which is offered by Automated Peritoneal Dialysis. But the available resources are expensive to use and hence common man cannot afford them; the knowledge regarding the choice of options is also not known to the masses.

To tackle this issue, the role and functions of kidneys in human excretory system are discussed in detail and various ways to carry dialysis are disclosed, most cost effective one being Automated Peritoneal Dialysis(APD). The advantages and disadvantages of APD are also discussed in the sections. Overall, APD machine is an efficient way to deal with ESRD problems.

VII. FUTURE WORK

The future work includes the circuit diagram, the software and hardware design, the assembly- model of the abdomen cavity to demonstrate the actual process of Automated Peritoneal Dialysis.

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