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Dialyzer Reprocessing Unit For Patient with End-Stage Renal Disease

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Abstract The purpose of this studies article is to broaden a low-price dialyzer reprocessing unit (DRU) prototype which could easy and sanitise hemodialysis dialyzers. Hemodialysis is a crucial scientific technique that enables patients with quit-level kidney disorder or renal failure eliminate waste products from their blood. Often known as a “artificial kidney,” the dialyzer is vital to blood filtration. There are kinds of dialysis machines: disposable and reusable. The reusable kind can best be used as much as 16 times. Such machines are high-priced to import, which makes it difficult for people in need to gain them. Thus, the goal of this studies is to create a low-cost DRU for cleaning and disinfecting dialyzers on the way to assure their efficacy and reduce expenses. Water, hydrogen peroxide, and other substances are managed through the DRU the use of a microprocessor.

Keywords: DRU, hydrogen peroxide, artificial kidney, microcontroller, renalin

INTRODUCTION

The prevalence of chronic kidney disease (CKD) is high enough in Pakistan that it poses a serious threat to public health. The expense of providing sufficient treatment for individuals with end-stage renal disease (ESRD) is a huge financial burden on the healthcare system, and the number of people with ESRD is rising quickly. Haemodialysis is the primary treatment for end-stage renal disease (ESRD) patients in Pakistan, although many patients cannot afford the treatment due to financial constraints. Using previously used dialyzers is one way to lessen the financial burden of dialysis [1].

There has been a rise in the usage of dialyzer reprocessing equipment in Pakistan as a viable, environmentally friendly alternative to disposable dialyzers. Before they may be reused for haemodialysis treatment, dialyzers must undergo a reprocessing procedure that includes cleaning, sanitising, and testing for good functioning. Each reprocessed dialyzer may be up to 50% less than buying a brand new one, so the savings add up quickly [2]. The quantity of medical waste produced by dialysis facilities is a major issue in Pakistan, and this waste may be mitigated by the use of reprocessed dialyzers. Dialyzer reprocessing has the potential to improve efficiency and reduce costs, however some people question whether it’s safe to reuse them. To guarantee patient safety, dialyzers must be reprocessed in accordance with applicable rules and laws. Both the dialyzer and the reprocessing equipment have a role in how well a reprocessing job turns out. For this reason, the creation of reprocessing facilities that reliably and regularly turn out high-quality reprocessed dialyzers is crucial [3].

The Pakistan Kidney and Liver Institute (PKLI) estimates that there are roughly 150,000 individuals in Pakistan with ESRD, with that number growing by 15-20% per year. Dialysis treatment might cost anything from PKR 20,000 to PKR 25,000 per month, which is out of reach for the vast majority of ESRD patients. This is the reason why there is such a high death rate among ESRD patients in Pakistan; many of them don’t get the care they need [4].

Because of the high rate of end-stage renal disease (ESRD) in Pakistan and the expensive cost of dialysis, reprocessed dialyzers may be an important tool in expanding treatment options for ESRD patients. Nonetheless, thorough testing and adherence to established norms and regulations are required to verify the safety and effectiveness of reprocessing [5]. Consequently, the purpose of this article is to offer a thorough analysis of dialyzer reprocessing facilities in Pakistan for people with ESRD. The present status of dialyzer reprocessing systems, their design, operation, and maintenance, and the safety and effectiveness of recycling dialyzers in the Pakistani setting will all be examined in this paper. This review’s results may be used to advocate for sustainable and cost-effective treatments for end-stage renal disease patients in Pakistan and other developing nations [6].

The problem addressed in this research paper is the high cost of importing dialyzer reprocessing units (DRUs) for patients with end-stage renal disease who require hemodialysis treatment. Haemodialysis is a critical medical procedure used to eliminate waste material from blood, and the dialyzer is a crucial component in blood filtering. While dialyzers are available in disposable and reusable formats, the latter can only be used a maximum of 16 times. The cost of importing DRUs is high, making it difficult for patients to access this

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life-saving treatment. Therefore, the problem statement of this research paper is to develop a cost-effective DRU that can clean and disinfect dialyzers, ensuring their effectiveness and reducing costs. The proposed DRU will use a microcontroller for process control and water, hydrogen peroxide, and renalin/formalin as cleansing and disinfectant agents. The DRU not only cleans the dialyzer but also stores the biological liquid with disinfectant for later use as protection against bacteria. By addressing this problem, this research aims to improve access to haemodialysis treatment for patients with end-stage renal disease.

BACKGROUND

There is an increasing public health problem in Pakistan due to the prevalence of chronic kidney disease (CKD), which affects an estimated 17.5% of the population aged 18 and above. Researchers have shown that the incidence of CKD is greater in rural regions than in urban ones, rising from 13.3% in the former to 16.8% in the latter. In Pakistan, diabetes, high blood pressure, and glomerulonephritis are the primary causes of chronic kidney disease.

The last stage of chronic kidney disease is known as end-stage renal disease (ESRD), and it is only treatable with renal replacement therapy (RRT). It is estimated that 85 percent of all RRT cases in Pakistan include haemodialysis, making it the most popular RRT modality for ESRD patients in Pakistan. An estimated 10,000 people in Pakistan develop ESRD every year, increasing the need for haemodialysis services. The majority of End-Stage Renal Disease (ESRD) patients cannot afford the exorbitant expense of dialysis, placing a heavy strain on the healthcare system and the patients themselves [7].

Many ESRD patients in Pakistan cannot afford dialysis, which is a major obstacle to receiving treatment. Most patients need at least two haemodialysis treatments each week, and a single session might cost between PKR 3,000 and PKR 5,000. The average Pakistani family cannot afford the monthly expense of PKR 20,000 to PKR 25,000 that this entails. Hence, many people don't get the care they need, and the death rate is significant [8]. One way to lower the cost of haemodialysis and increase access to healthcare for people with ESRD in Pakistan is via the practise of dialyzer reprocessing. Before they may be utilised for another patient's haemodialysis treatment, dialyzers must undergo a procedure known as "reprocessing," which entails cleaning, sanitising, and testing the devices [9]. Each reused dialyzer may save up to 50% compared to the price of a brand new one thanks to reprocessing. The quantity of medical waste produced by dialysis facilities is a major issue in Pakistan, and this waste may be mitigated by the use of reprocessed dialyzers.

In recent years, the number of patients in Pakistan who have opted to utilise reprocessed dialyzers has risen. The percentage of reprocessed dialyzers in Pakistan rose from 4.4% in 2014 to 15.3% in 2018, according to a report published in the Saudi Journal of Kidney Diseases and Transplantation. Reprocessing has been on the rise due to the increasing demand for dialysis and the need to lower healthcare costs for ESRD patients [10]. Dialyzer reprocessing has the potential to improve efficiency and reduce costs, however some people question whether it's safe to reuse them. To guarantee patient safety, dialyzers must be reprocessed in accordance with applicable rules and laws. Both the dialyzer and the reprocessing equipment have a role in how well a reprocessing job turns out. Reliable and reliable reprocessing systems that generate high-quality reprocessed dialyzers are, thus, crucial [11].

Manufacturing Cost and Availability

Due to a lack of domestic production capabilities, refurbished dialysis machines are in short supply in Pakistan. Since most dialyzers in use in Pakistan are imported from other nations, the price of haemodialysis in the country is high. The Pak Medical Supplies (PMS) and the Advanced Engineering Research Organization (AERO) are only two of the indigenous dialyzer producers in Pakistan that are dedicated to lowering the price of dialysis by creating high-quality machines at more affordable prices [12].

Since 1998, dialyzers have been produced by PMS, a Pakistani company specialising in the production of medical equipment. Several different types of dialyzers for haemodialysis are manufactured by the business. They include hollow fibre and flat sheet dialyzers. PMS's dialysis machines are reliable and up to par with global norms. By manufacturing recycled dialyzers, which are 50% cheaper than new ones [13], the firm has also been aiming to lower the cost of dialysis.

During the year 2000, scientists at Pakistan's AERO have been improving dialysis machines. The company has created several different types of medical technology, such as dialyzers and haemodialysis machines. AERO's dialyzers are durable and made to be reused, making them an economical choice for haemodialysis clinics. The group has also been trying to increase access to dialysis machines in Pakistan by creating a domestic production plant [14].

When used, recycled dialyzers may drastically cut the price of haemodialysis in Pakistan, making treatment more accessible to those with end-stage renal disease. Dialysis in Pakistan using recycled dialyzers is 42% less expensive than using new dialyzers, according to a research published in the Saudi Journal of Kidney Disorders and Transplantation. Patients with ESRD who can't afford the high price of dialysis with modern dialyzers may benefit greatly from this price drop [15].

Healthcare for ESRD patients in Pakistan is already hampered by a lack of reprocessed dialyzers available in hospitals. Most

hospitals in Pakistan get their reprocessed dialyzers from outside companies since they lack in-house reprocessing machines. Dialyzer shortages and higher haemodialysis costs are possible results of this. Establishing reprocessing facilities inside hospitals in Pakistan is crucial to increasing access to refurbished dialysis machines. Haemodialysis for patients with ESRD would be cheaper if there was a reliable supply of reprocessed dialyzers. Unfortunately, many hospitals in Pakistan may struggle to fund and staff reprocessing facilities because to the high costs and technical complexity involved.
The process of dialysis and dialyzer reprocessing unit

In the case of individuals with End Stage Renal Disease, dialysis is a therapy that may prolong their lives (ESRD). Dialysis is a technique in which the patient's blood is filtered through a machine called a dialyzer, which eliminates fluid and waste items from the patient's blood. An efficient dialyzer is crucial to successful haemodialysis therapy.

A bundle of hollow fibres or flat sheets is the basis for the medical equipment known as a dialyzer. Dialysate is a specific solution that runs around the fibres or sheets as the patient's blood flows through them. Dialysate is used to purge the blood of toxins because of the electrolytes and other chemicals it contains. Dialyzer reprocessing include preparing the device for reuse by cleaning, sanitising, and testing it. As compared to buying brand-new dialyzers, reprocessing may drastically cut down on the price of haemodialysis. The process of reprocessing consists of many phases: preparation, cleaning, testing, disinfection, and sterilisation [16].

Cleaning the dialyzer by hand is the first step in reprocessing. To rid the dialyzer of dirt, blood clots, and other pollutants, a specific cleaning solution is used in conjunction with physical cleaning. We then use clean water to remove the cleaning solution. The integrity of the dialyzer is checked after cleaning. Dialyzer pressure and flow rates are being measured to check for leaks and clogs as part of the testing process. A non-working dialyzer is thrown away if any problems are found throughout the evaluation process. When a dialyzer has been thoroughly tested, it is disinfected using a specific solution that eliminates any germs or viruses that may have accumulated on the material's fibres or sheets throughout the testing process. The dialyzer is washed with fresh water after disinfection to get rid of any leftover chemicals [17]

Dialyzer sterilisation is the last stage in the reprocessing procedure. The dialyzer must be sterilised to eliminate the risk of the patient contracting an illness from using it. Steam sterilisation, in which the dialyzer is exposed to high-temperature steam, is the most prevalent form of sterilisation employed in dialyzer reprocessing. Dialyzer reprocessing is governed by ISO and AAMI standards (AAMI). These guidelines guarantee that dialyzers that have been reconditioned are fit for use in haemodialysis. Reprocessed dialyzers have been proved to be a safe and effective addition to haemodialysis treatments. One research found that haemodialysis patients who used recycled dialyzers did not have a higher risk of infection or other problems.

Symptoms of renal failure

When the kidneys stop working effectively, a condition known as end-stage renal disease (ESRD) sets in. This disease causes the body to retain waste products and fluids, which may have devastating health consequences. Depending on the degree of kidney failure, symptoms might include:

- Fatigue and weakness - Patients with ESRD may experience extreme fatigue and weakness due to the build-up of waste products in the body.
- Nausea and vomiting - The accumulation of waste products in the body can cause nausea and vomiting, which can be severe in some cases.
- Loss of appetite - Patients with ESRD may experience a loss of appetite due to the build-up of waste products in the body.
- Swelling - The accumulation of excess fluid in the body can cause swelling in the legs, feet, and ankles.
- Shortness of breath - The build-up of fluid in the lungs can cause shortness of breath and difficulty breathing.
- Itching - The accumulation of waste products in the body can cause itching, which can be severe in some cases.
- Muscle cramps - Patients with ESRD may experience muscle cramps due to electrolyte imbalances in the body.
- High blood pressure - The kidneys play a critical role in regulating blood pressure, and the failure of the kidneys can lead to high blood pressure.
- Changes in urine output - Patients with ESRD may experience a decrease in urine output or may stop producing urine altogether.

Peritoneal Dialysis

Patients with end-stage renal disease (ESRD) also have the option of undergoing peritoneal dialysis, which includes the use of the peritoneum as a natural filter for waste and surplus fluids. To do this, a specific fluid called dialysate is administered into the abdominal cavity through a catheter. Dialysate is left in the abdomen for a certain period of time to flush out toxins and extra fluids. In contrast to conventional dialysis, peritoneal dialysis may be performed at home, giving patients more control over their health and well-being [18].

Steps of Dialyzer Reprocessing

Dialyzer reprocessing involves several steps to ensure that the dialyzer is properly cleaned and disinfected before reuse. The steps include:

- Disconnection and removal of the dialyzer from the patient's bloodline.
- Flushing the dialyzer with saline solution to remove any remaining blood and debris.

- Pre-cleaning the dialyzer with a special enzymatic cleaner to remove any remaining organic material.
- Disinfection of the dialyzer with a germicidal agent such as peracetic acid or hydrogen peroxide.
- Rinsing the dialyzer with sterile water to remove any remaining cleaning or disinfectant agents.

How Long Dialyzer Can be Reused?

Reusing dialyzers reduces healthcare costs, which is especially important in countries like Pakistan with limited access to medical supplies. Dialyzers may be used for varying amounts of time depending on a variety of criteria such as the kind of dialyzer, the number of reprocessing cycles, and the specific requirements of each patient. The average number of times a dialyzer is used in a single patient in Pakistan is six, with some individuals using them even longer.

Total Cell Volume or TCV

The total cell volume (TCV) is a measure of the size of the dialyzer membrane and is an important factor in determining the efficiency of dialysis. The TCV is calculated by multiplying the surface area of the dialyzer membrane by its thickness. A larger TCV is associated with better clearance of waste products and excess fluids from the body.

Urea Reduction Ratio or URR

The urea reduction ratio (URR) is a measure of the effectiveness of dialysis in removing urea, a waste product of protein metabolism, from the body. The URR is calculated by comparing the amount of urea removed during a dialysis session to the amount of urea present in the patient's blood before the session. A higher URR indicates more effective removal of urea and better clearance of waste products.

Kt/V

Kt/V is another measure of the effectiveness of dialysis in removing waste products from the body. Kt/V takes into account both the clearance of urea and the time over which the dialysis occurs. A higher Kt/V indicates more effective removal of waste products and better overall dialysis outcomes.

LITERATURE REVIEW

The consequences of dialyzer reuse on mortality have not been studied rigorously. Galvao et al. (2012) summed up the research on the benefits of reusing dialyzers instead of buying new ones for ESRD patients. They looked through major nephrology associations' yearly conference proceedings as well as MEDLINE, Embase, CINAHL, SciELO, LILACS, USRDS ADR, and university theses databases. The search yielded 1,190 papers; however, only 14 were included in the meta-analysis. Hypochlorite, formaldehyde, glutaraldehyde, and peracetic acid were utilised as disinfectants during dialyzer reprocessing. Studies' evidence was extremely weak, if any at all. Several research has failed to find any significant differences between study groups. Disinfectant type, duration of observation, and location of treatment all had an impact on studies finding statistically significant differences. It was shown that there were no statistically significant differences between the usage of reusable and disposable dialyzers in terms of mortality among patients with ESRD. Further robust research, such as randomised clinical trials, is needed to definitively determine the efficacy and safety of dialyzer reuse.

The research by Held et al. (1994) tracked haemodialysis patients for a full year to see whether or not dialyzer reuse practises were associated with an increase in mortality. Data on Medicare patients' demographics, outcomes, and dialyzer reuse were linked with information from the CDC's yearly survey of dialysis-related disorders. They investigated data from the United States Medicare haemodialysis population of never-transplanted patients treated in freestanding dialysis facilities using mostly conventional dialyzers on January 1, 1989, and January 1, 1990. Proportional hazards models were used to regress patient, dialysis unit, and reuse measures against time to death, transplant, and other censoring on December 31 of each year. Dialysis unit mortality rates adjusted for age, race, and diagnosis were also regressed on metrics of dialysis units and reuse using weighted least squares methods. Dialysis patients who were treated in facilities that disinfected their equipment using peracetic acid, hydrogen peroxide, an acetic acid combination, or glutaraldehyde had a greater death rate than those whose facilities utilised formalin or didn't reuse dialyzers. In comparison to patients treated in non reuse dialysis facilities, the relative risk of death for glutaraldehyde was 1.17 ($P = 0.010$), and for the peracetic acid combination, it was 1.13 (P 0.001). As compared with the non-reuse control group, formalin had a 1.06 ($P = 0.088$) higher relative risk. Dialyzer reuse with specific germicides was related with a considerably increased mortality risk, after taking into account a number of patient and dialysis unit factors. The cause of this increased risk is unknown, but it may account for many preventable deaths annually. These mortality hazards would only be detectable in a big, nationally based study of this kind. The table below compares 5 different publications related to the topic.

Table 1: Comparison of 5 different publications

Paper title	Authors	Study Design	Main Findings	Limitations
Clinico-Epidemiological Profile of Dialysis services in Karnataka, India – a multicentric exploratory study	Anupama et) (al., 2022	Cross-sectional study	Inadequate availability of dialysis machines, high burden of infections, and lack of trained healthcare workers in .Karnataka, India	Lack of comparison with dialysis services in other regions of India or other countries. Small sample .size

Prevalence and genotype distribution of hepatitis C virus within Hemodialysis units in Thailand: Role of HCV core antigen in the assessment of viremia	Chuaypen et) (al., 2022	Cross-sectional study	High prevalence of HCV infection in hemodialysis units in Thailand, with predominance of HCV genotype 3. HCV core antigen had high sensitivity and specificity in .detecting HCV viremia	Small sample size. No data on clinical outcomes of patients with HCV infec-.tion
Optimal time for recirculation with ultrafiltration to remove disinfectant in reused dialyzer	Itthipong-) sakul et al., (2022	Experimental study	Recirculation with ultrafiltration for 40 minutes was the most effective in removing disinfectant .from reused dialyzers	No data on clinical outcomes of patients using reused dialyzers. Small .sample size
Reverse epidemiology for lipid disorders in hemodialysis-dependent patients: Role of dilutional hypolipidemia	Kumthekar) (et al., 2022	Cross-sectional study	Hemodialysis-dependent patients had significantly lower lipid levels than the general population, and low lipid levels were associated with better survival. Dilutional hypolipidemia due to large volume of ultrafiltration during dialysis was the main cause of low lipid .levels	Lack of data on lipid-lowering medication use. No data on the effect of lipid levels on clinical outcomes other than .survival
Effect of dialyzer reuse on the activity of paraoxonase 1 in patients on Hemodialysis	Miguita Jr.) (et al., 2022	Cross-sectional study	Reuse of dialyzers was associated with decreased paraoxonase 1 activity, which could increase the risk of cardio-.vascular disease	Small sample size. Lack of data on clinical outcomes of patients with decreased paraoxonase 1 ac-.tivity

MATERIALS AND METHODS

The goal of this research was to create a dialysis machine prototype capable of replacing a human kidney. Electronic components for instrument control and standard components of a development board are included in the reprocessing process. The power supply, the dialyzer, the Arduino UNO board, the basic output circuitry (LEDs, a 4 channel relay module, three sets of solenoid valves and pumps, an alphanumeric LCD display with twenty sets of four digits, an I2c packing for the display, a push button, a pneumatic valve, pneumatic tubes for piping, electrical wires, and a barrel jack), and so on. The dialyzer is a replacement for a real kidney, performing all the same necessary tasks. By using a 4-channel relay and an Arduino UNO board, we are able to control the flow of sterilising compounds and postpone their activation. Arduino requires a power source in order to be programmed. This device takes in 220v AC and converts it to 12v to power the water pump and relay module.

Fluids may also be changed with the use of a pneumatic valve. Typically, the solenoid valve, an electro-mechanical valve, is used to regulate the transfer of chemicals from the storage area to the pump. To operate the solenoid valves and pumps, a 4-channel relay is employed to activate and deactivate the appropriate circuits. The fluids within a tube are pushed forward with the help of the pumps. The process data is shown on an alphanumeric LCD connected to the Arduino board through an I2c socket. Lastly, electric current is carried through wires and the operation is initiated by pressing buttons. Moreover, components that are used in this project are mentioned in block diagram below.

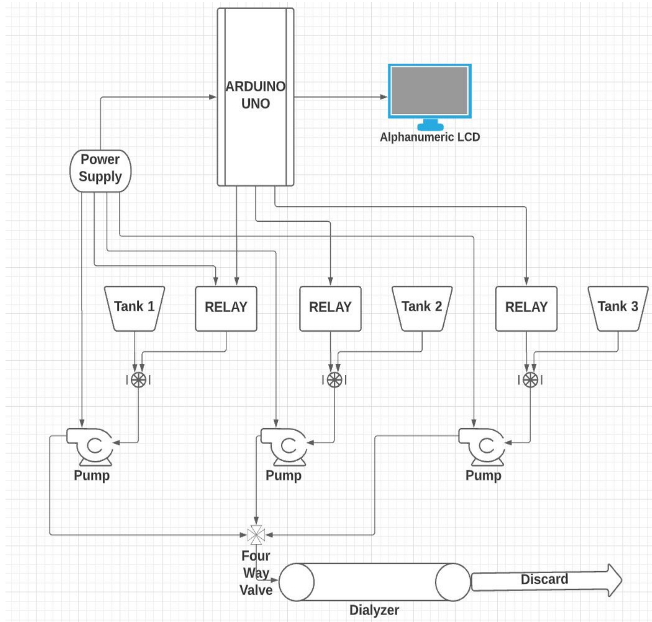


Figure 1: Block Diagram

The dialyzer reprocessing unit's fluid tank is split into three equal sections, with one section containing each of three different solutions. These sections are linked together by tubing and fitted with solenoid valves to regulate the flow of fluids. Pneumatic valves and tubing link the solenoid valves to their associated pumps, allowing fluid to be pumped into the dialyzer. There are three stages to the sterilising process: The dialyzer is purified and sanitised by a three-step process including the sequential passage of reverse osmosis (RO) water, hydrogen peroxide, and formaldehyde. The sterilising procedure is managed by an Arduino board, which sends commands to a relay to activate the solenoid valve and pump in a predetermined sequence and at a certain delay. When the sterilising procedure has been completed, the pump and flow mode are switched off. The alphanumeric LCD shows the whole sterilising procedure as it occurs. The procedure is started by pressing the button and is managed by the Arduino board. Pumps, Arduino, and relays all get their electricity from the same source. The fluid tank of the dialyzer reprocessing unit is divided into three sections, and from there fluids may be pumped into the dialyzer through a pneumatic valve and tubing. The Arduino board manages the sterilising process and provides feedback on the LCD screen. The necessary voltage for the system comes from the power source. This is a complete inventory of all the tools used:

Power Supply

The power supply is an essential component of the Dialyzer Reprocessing Unit, providing power to all the other components of the unit. The power supply used in the unit is likely to be a DC power supply, capable of delivering a stable voltage to power the other electrical components. The power supply must also be capable of delivering sufficient current to power all the components, and it must be designed to operate safely and reliably. It's main function is to convert 220V AC to 12V.

Dialyzer

The Dialyzer is the core component of the Dialyzer Reprocessing Unit, which is used to filter the blood of patients with End Stage Renal Disease (ESRD). It is a medical device that is used to remove waste products from the blood and excess fluid from the body. The Dialyzer typically consists of two chambers separated by a semi-permeable membrane, through which the blood flows, approximately 30 centimetres in length. The Dialyzer Reprocessing Unit works by cleaning and reusing the Dialyzer, thereby reducing the cost of treatment and helping to prevent medical waste. The figure below shows a dialyzer.

Figure2: Dialyzer

Arduino UNO board

One such microcontroller board is the Arduino UNO, which utilises the ATmega328P. An open-source electronics platform, it's used to create anything from low-level sensors to complicated mechanical systems. In addition to its widespread usage in prototyping and do-it-yourself (DIY) endeavours, the board's programmability inside the Arduino IDE also contributes to its popularity. The Arduino UNO board is responsible for displaying data on the LCD screen and controlling the functioning of the different components in the Dialyzer Reprocessing Unit, such as the pumps and valves. In order for the Arduino to work, a 5 volt power source must be attached to it. Lights, motors, and sensors are just some of the many things that can be controlled by the board's 14 digital input/output pins. It can also read data from sensors that provide analogue output thanks to its six analogue inputs. The ceramic resonator on the Arduino UNO board operates at 16 MHz, providing the microcontroller with a stable clock signal. The board's USB port makes it simple to connect it to a computer, where it can then be programmed using the Arduino IDE (IDE). The ICSP header enables the board to be programmed with an external programmer, and the power port may be used to power the board with an AC adapter.
The board has a reset button for resetting the microcontroller and a USB port for uploading new code. Inexpensive, versatile, and user-friendly, the Arduino UNO is a microcontroller board packed with useful capabilities for making all sorts of electrical gadgets. The board is perfect for those who are just starting out in electronics and computer programming because of its intuitive design and straightforward programming language. In addition, it has cutting-edge functions and features that make it an excellent choice for experts who need a robust but adaptable environment in which to work on their projects. The figure below shows an ARDUINO UNO.

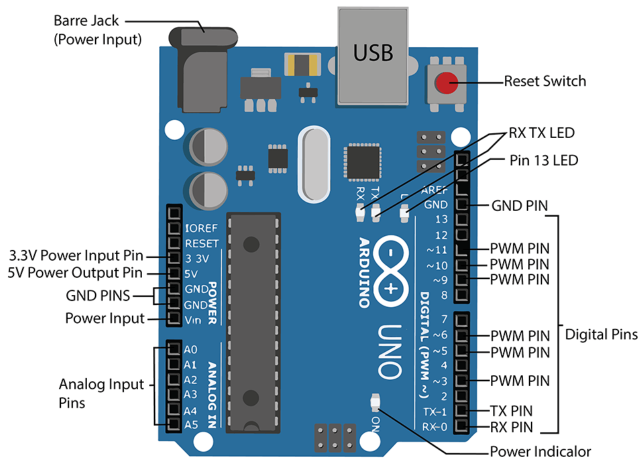


Figure 3: Arduino UNO

Basic output circuitry

Basic output circuitry such as LEDs are electronic components used to display information and status of the unit to the operator. LEDs can be used to indicate the power status, the status of pumps or valves, or to provide other information. LEDs are reliable and low-cost components and are commonly used in many electronic devices.

4 Channel Relay Module

A relay is an electronic switch that is controlled by an electrical signal. The 4 Channel Relay Module is used to control high voltage and current devices, such as pumps and solenoid valves. The Arduino UNO board controls the relay module, which in turn controls the pumps and valves, allowing the unit to operate safely and reliably. The figure below shows a 4 Channel Relay Module.

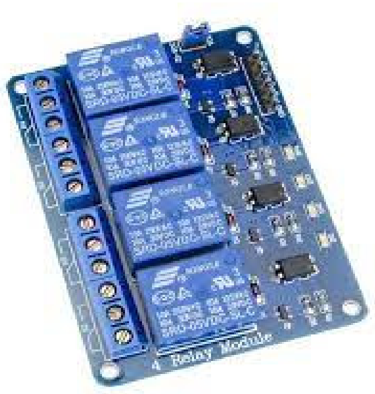


Figure 4: 4 channel relay module

Pneumatic valve

A pneumatic valve is a type of directional control valve that is primarily designed to control the flow of fluids in a pneumatic system. These valves are capable of maintaining a consistent pressure level and are widely used in various industries such as manufacturing, automotive, and aerospace. The main function of a pneumatic valve is to switch the flow of fluids on and off, as well as to precisely control the flow rate and pressure. This can range from simple on/off functions to complex proportional control of pressure and flow.

One of the major benefits of using a pneumatic valve is that it is cost-effective, durable, and reliable. These valves are built to withstand harsh operating conditions and require minimal maintenance over their lifetime. Additionally, they come with a built-in locking system that secures them in place without the need for external components. The figure below shows a pneumatic valve.

Figure 5: Pneumatic valve

Solenoid valves (3x)

Solenoid valves are electromechanical devices used to control the flow of fluids in the Dialyzer Reprocessing Unit. The solenoid valves are controlled by the Arduino UNO board and are used to direct the flow of cleaning solution and water into and out of the Dialyzer. The solenoid valves must be chosen based on their compatibility with the cleaning solution and water used in the unit. The figure below shows a solenoid valve.

Figure 6: Solenoid valve

Dialyzer Nipro

The Dialyzer Nipro is a specific type of Dialyzer used in the Dialyzer Reprocessing Unit. The Nipro Dialyzer is a high-quality, medical-grade device that is designed to meet the strictest standards of quality and safety. The Nipro Dialyzer has a semi-permeable membrane that allows the flow of blood through it, while removing waste products and excess fluid.
Pumps

Three pumps are used in the Dialyzer Reprocessing Unit to pump the cleaning solution, water, and other fluids into and out of the Dialyzer. Since this is a prototype unit, small pumps capable of generating low pressure are used. The pumps are controlled by the Arduino UNO board and are chosen based on their compatibility with the fluids used in the unit. The figure below shows the pump used.

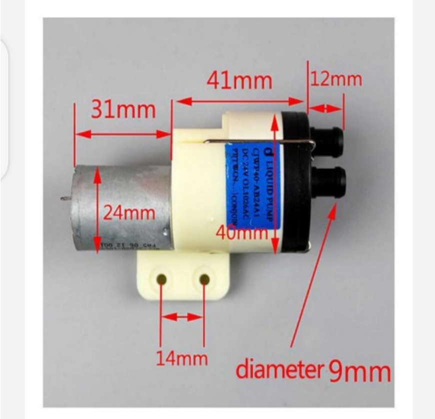


Figure7:Pump

Alphanumeric LCD (20x4)

In real time, information may be shown to the user through the Alphanumeric LCD (20x4). A maximum of 20 characters may be shown over four lines on the screen. An I2C packaging module controls the device, facilitating simple interaction between the LCD and the microcontroller. Important data, such as the current reprocessing cycle status, remaining processing time, and error warnings, may be shown to the user on the screen. An essential part of the reprocessing machine, the alphanumeric LCD displays process data in real time, allowing the operator to verify that everything is running well. An 18-segment display, consisting of a 5 by 7 dot matrix, can show both alphabets and numbers, in contrast to 7-segment displays, which can only show numbers in decimal and hexadecimal format. Every one of the 18 LED segments that make up the 18-segment display may be controlled independently of the others. The display is laid out in a 5x7 grid. As compared to 7-segment screens, this enables the display of more complicated characters. The figure below shows an alphanumeric LCD.

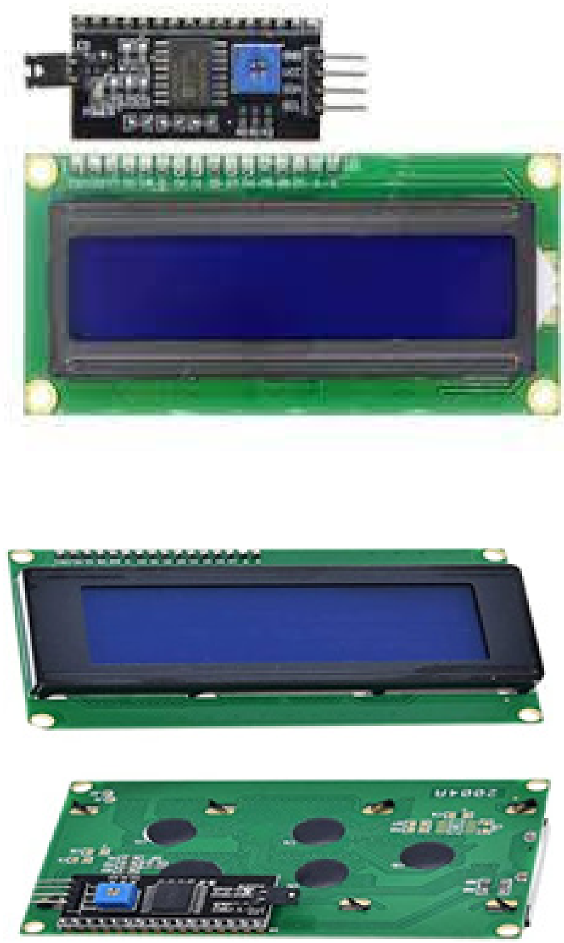


Figure 8 : Alphanumeric LCD

I2c Packing for LCD

The I2C packaging for LCD is a module that facilitates I2C communication between the microcontroller and the LCD screen. This module provides a connection between the microcontroller and the LCD screen, making it simple to customise the screen's appearance. It makes coding the screen easier by offering libraries and methods that may be used to show data such as text and numbers. Having the microcontroller talk to the LCD display and provide relevant data to the user is made possible by the I2C packaging for LCD, making it a crucial part of the reprocessing unit. Better use of the Arduino board's digital I/O pins is possible when talking to the alphanumeric LCD module using the I2C or SPI protocol. Whereas the SPI standard requires four pins, the I2C protocol only needs two (SDA and SCL) (MOSI, MISO, SCK, and SS). This frees up extra pins for various uses, such as attaching more sensors or actuators. The figure below shows an I2c packing for LCD.

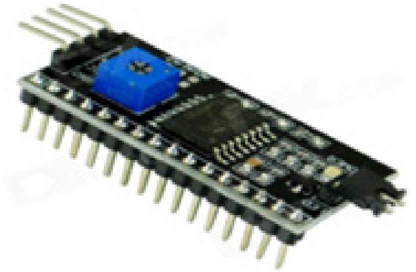


Figure 9: I2c Packing

Push button

The push button is a momentary switch that is used to initiate the reprocessing cycle. It is typically located on the front panel of the unit and is used to start the cycle once the dialyzer has been properly prepared. When the button is pressed, it sends a signal to the microcontroller which then initiates the reprocessing cycle. The push button is a critical component of the reprocessing unit as it ensures that the process is initiated only when the dialyzer is properly prepared. The figure below shows a push button.

Figure 10: Push button

Pneumatic Tubes for piping

The pneumatic tubes are used to transport fluids within the reprocessing unit. They are typically made of a flexible plastic material that is resistant to the chemicals used in the process. The pneumatic tubes are an essential component of the reprocessing unit as they transport the fluids needed for the process. The figure below shows the pneumatic tubes.

Figure 11: Pneumatic tubes

Electrical Wires

The electrical wires are used to connect the various components of the reprocessing unit. They are typically color-coded and are used to transmit power, control signals, and data between the different components of the unit. The electrical wires are a crucial component of the reprocessing unit as they ensure that the various components are connected correctly and that the unit operates as intended. The figure below shows the electrical wires.

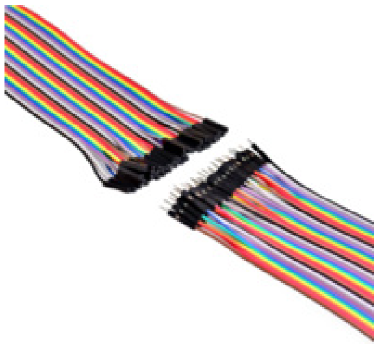


Figure 12: Electrical wires

Barrel Jack

The barrel jack is a type of power connector that is used to supply power to the reprocessing unit. It is typically located on the back panel of the unit and is used to connect the unit to a power supply. The barrel jack is an essential component of the reprocessing unit as it supplies power to the various components of the unit and enables it to operate correctly.

Metal Casing

An integral part of every project is the casing, which serves to enclose and safeguard the project's electrical components. The Arduino board, LCD module, solenoid valves, and pumps all fit snugly within their custom-made enclosures. A 3D model was used to guide the cutting and bending of 20-gauge steel sheet into a rectangular casing.

As stainless-steel sheet is so resilient, lightweight, and corrosion-resistant, it was the material of choice. The steel sheet had a red oxide coating sprayed to it to prevent corrosion, and then an off-white paint was used to cover it up. This coating helps prevent the steel sheet from rusting and corrosion due to moisture. The fluid tank and the solenoid valves and pumps were fastened to two plates that were put within the housing. These plates were screwed firmly into place on the housing to prevent any wiggle room or separation. The case is constructed in a way that facilitates access to the internals for the purposes of servicing or repairing them. The figure below shows the metal casing.

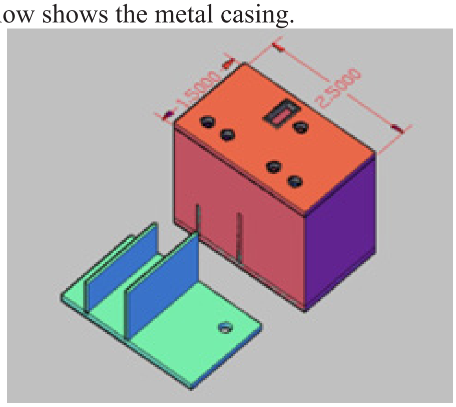


Figure 13: Metal casing

Fluid Tank

Dialyzer Reprocessing Unit fluid tanks for end-stage renal disease patients are built of glass for several reasons. There are three sections in the tank: one for water, one for hydrogen peroxide, and one for Renalin/Formalin. Glass was selected because it is robust and heavy, making it suitable for smaller tanks rather than larger ones. Moreover, glass is scratch-resistant, making it simple to disinfect the tank and prevent the growth of germs before each dialysis session.

The glass tank is an economical option since it is less expensive than alternatives like stainless steel or plastic. The 8mm diameter centre holes in each compartment enable tubes connecting the pumps and valves to pass through, and the tank's glass construction makes it simple to visually check the contents within. The whole fluid tank is sealed with silicon gel to prevent leaking and keep all fluids where they should be. Ultimately, glass was chosen as the material for the fluid tank in the Dialyzer Reprocessing Unit due to its durability, scratch resistance, cost efficiency, and simplicity of cleaning. The figure below shows the fluid tank.

Figure 14: Fluid tank

SOFTWARE PROGRAMMING (MICROCONTROLLER)

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>

LiquidCrystal_I2C lcd(0x27, 20, 4);
int buttonState = 0;

void setup()
{
  lcd.begin(20,4);
  lcd.init();
  lcd.backlight();
  pinMode(13, OUTPUT); // Output pin for renalin
pinMode(12, OUTPUT); // Output pin for h202
pinMode(11, OUTPUT);// Output pin for  water
pinMode(8, INPUT);//INPUT FOR BUTTON

 lcd.clear();
  lcd.setCursor(4, 0);
  lcd.print("***WELCOME***");
  delay(2000);
  lcd.clear();
  lcd.setCursor(1, 0);
  lcd.print("...PRESS BUTTON...");
  lcd.setCursor(2, 2);
  lcd.print("...TO START...");
  }
```

```
void loop()
{
  int buttonState = 0;

buttonState = digitalRead(8);

  // check if the pushbutton is pressed. If it is, the buttonState is HIGH:
  if (buttonState == HIGH) {

  lcd.clear();
  lcd.setCursor(3, 0);
  lcd.print("..STARTING IN..");
  delay(2000);
  lcd.clear();
  lcd.setCursor(6, 0);
  lcd.print(".. 03 ..");
  delay(1000);
  lcd.clear();
  lcd.setCursor(6, 0);
  lcd.print(".. 02 ..");
  delay(1000);
  lcd.clear();
  lcd.setCursor(6, 0);
  lcd.print(".. 01 ..");
  delay(1000);

  digitalWrite(11, LOW);
  digitalWrite(13, LOW);

  digitalWrite(12, LOW);

  lcd.setCursor(1, 0);
  lcd.print("WATER FLOW MODE ON");
digitalWrite(11, HIGH);
digitalWrite(12, LOW);
digitalWrite(13, LOW);

delay(10000);
  lcd.clear();

  lcd.setCursor(2, 0);
  lcd.print("......");
delay(1000);
  lcd.clear();
  lcd.setCursor(1, 0);
  digitalWrite(12, LOW);
  digitalWrite(11, LOW);
  lcd.print("WATER FLOW MODE OFF");
delay(2000);
  lcd.clear();
  lcd.setCursor(2, 0);
  lcd.print(" WAIT PLEASE!");
delay(2000);

lcd.clear();
digitalWrite(12, HIGH);
digitalWrite(13, LOW);

digitalWrite(11, LOW);
lcd.clear();
  lcd.setCursor(1, 0);
  lcd.print("H2O2 FLOW MODE ON ");
delay(10000);
lcd.clear();
  lcd.setCursor(2, 0);
  lcd.print("...... ");
delay(3000);
  lcd.clear();

  lcd.setCursor(1, 0);
digitalWrite(12, LOW);
  lcd.print("H2O2 FLOW MOOD OFF ");
delay(2000);
digitalWrite(13, HIGH);
digitalWrite(12, LOW);

digitalWrite(11, LOW);
lcd.clear();

  lcd.clear();
lcd.setCursor(1, 0);
  lcd.print("Renalin FLOW MODE ON ");
delay(10000);

lcd.clear();
  lcd.setCursor(2, 0);
  lcd.print("...... ");
delay(3000);
  lcd.clear();

  lcd.setCursor(1, 0);
digitalWrite(13, LOW);
  lcd.print("Renalin FLOW MOOD OFF ");
delay(2000);
  lcd.clear();
  lcd.setCursor(2, 0);
  lcd.print(" WAIT PLEASE!");
delay(1000);
  lcd.setCursor(2, 0);
  lcd.print(" ..PROCESS IS.. ");
  lcd.setCursor(3, 1);
  lcd.print(" ..COMPLETED.. ");
delay(2000);
digitalWrite(13, LOW);
digitalWrite(12, LOW);
digitalWrite(11, LOW);
delay(1000);
 lcd.clear();
  lcd.setCursor(1, 0);
  lcd.print("...PRESS BUTTON...");
  lcd.setCursor(2, 2);
  lcd.print("...TO START...");
  }
}
```

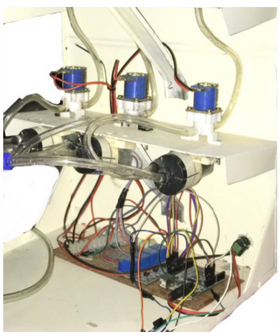
RESULTS

Dialyzers used by patients with ESRD may be effectively cleaned and sterilised by the Dialyzer Reprocessing Unit, as shown by the findings of our research. The dialyzer is first flushed with R.O water to eliminate any remaining traces of blood, the first of three stages in the cleaning and sterilising procedure. Hydrogen peroxide is then pumped through the dialyzer to kill any germs that may have gotten inside. Pathogen-resistant Renalin is pumped into the system in the third stage to keep microorganisms at bay. Solenoid valves are activated on and off by relays, which regulate the flow of fluids through the system.

The successful operation of the project is shown by the system circuit results. The sterilising process is being shown in real time on an alphanumeric LCD screen. In the figure below, we see the LCD's displayed message. The figure below shows the display.

Figure 15: Display

The figures below depict the internal circuitry of the system, outlining the interconnections between its many parts. The Arduino UNO board, LCD display, relays, solenoid valves, pumps, and power supply are all included in the circuit design.



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The figure below shows the internal circuitry.

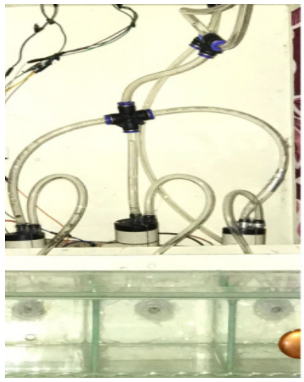

Figure 16: Internal circuitry

If you look at the following figure, you can see what happens when the circuitry is activated. The flow of R.O water, the first step of the sterilising procedure, is shown on the screen. The Arduino board activates the relays, which in turn on the solenoid valve and pump, allowing R.O water to begin flowing through the dialyzer. The figure below shows the working result.

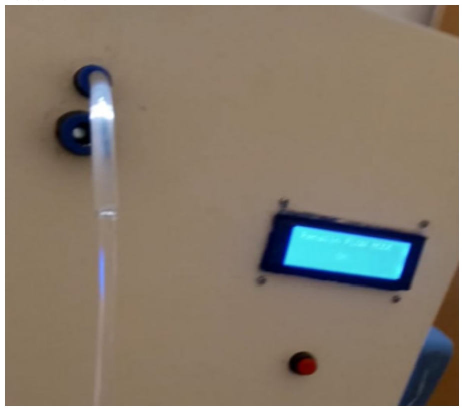

Figure 17: Working result

The results are shown in the figure below. Dialyzer reprocessing unit is doing a good job of disinfecting and sanitising the device, and fluid is being properly introduced through the pneumatic valve and tubing. The figure below shows the final results.

Figure 18: Results

Figure below depicts the finalised Dialyzer Reprocessing Unit design. Glass fluid tank is sealed with silicon gel to prevent leaking, and the shell is composed of 20-gauge steel sheet, which is lightweight and sturdy. The system is built to endure, thanks to the careful design. The figure below shows the final casing.

Figure 19: Final casing

Patients with ESRD have a new option for keeping their dialyzers clean and germ-free thanks to the Dialyzer Reprocessing Unit. Our research shows that this technique successfully cleans the dialyzer of any trace of blood and eliminates the threat of infectious microorganisms. The completed product is sturdy and long-lasting, making it a good option for those with ESRD.

DISCUSSION

The major aim of this study was to lower the cost of the dialyzer so that patients with ESRD who are now unable to get therapy may do so. If established guidelines developed by the Association for the Advancement of Medical Instrumentation (AAAMI) are followed, reusing dialyzers is considered safe and effective. While haemodialysis is the treatment of choice for renal failure, it is too costly for many patients in developing countries like Pakistan. As a result, efficient dialyzer reuse should be encouraged to lessen treatment abandonment caused by bureaucratic burdens [19]. This work included developing a system for recycling old dialyzers so that they may be used again and again. Dialysers were washed with R.O. water, disinfected with hydrogen peroxide, filled with Renalin fluid, labelled, and kept in a dialyzer reprocessing facility. A unique fluid including RO water, hydrogen peroxide, and Renalin was poured into the three chambers.

A microprocessor was used to trigger the relay and hence open and shut the solenoid valve. The microprocessor sends signals to the relay, which in turn opens the solenoid valves, allowing liquid to flow. There is a limit of one wall open at a time. The 50 volt DC supply low pressure pump is coupled to a solenoid valve that allows for a flow rate of 1.5 litres per minute. This prototype uses a pneumatic tube, which doesn't clog and enables fluids to flow freely; an LCD screen shows what fluid is being transferred and whether or not the operation is complete. Patients in developing countries may be certain that they are receiving safe and effective treatment thanks to real-time monitoring that guarantees quality control and reprocessing procedures are being followed [20].

Reusable dialysis equipment may provide adequate dialysis much like disposable equipment. Patients with ESRD may be able to save a lot of money by recycling their used dialyzers. The availability of dialysis therapy may be increased by installing a dialyzer reprocessing machine in hospitals and clinics, which is particularly important in countries with low per capita healthcare spending.

Reusing dialyzers has the potential to save money for ESRD patients, as shown by this experiment. The dialyzer reprocessing equipment is an efficient, low-cost, and risk-free way to recycle used dialyzers. To avoid any possible health risks, it is crucial that the procedures for dialyzer reprocessing be properly adhered to. Especially in low-income countries with little medical resources, the introduction of a dialyzer reprocessing machine into hospitals and clinics might assist increase patient access to dialysis therapy [21].

CONCLUSION

If your kidneys have reached end-stage renal disease (ESRD) and are no longer able to filter waste and excess fluid from your body, dialysis may be a life-saving therapy option. Because of the exorbitant cost of dialyzers, many people in need of dialysis treatment cannot afford it. Nevertheless, with the advent of dialyzer reprocessing facilities, dialyzers may be used again without losing their effectiveness. When a dialyzer has to be reprocessed, it is cleaned, sterilised, and filled with a solution like Renalin [22].

This study presents a prototype for a reusable dialyzer that can be used up to 16 times. The Arduino microprocessor at its heart manages the prototype's functioning through relays, opening and shutting solenoid valves to direct the necessary fluid through the dialyzer.

Dialyzer reprocessing is an established part of dialysis care in the United States, having been used there in the 1960s. In low-income countries, where the cost of treatment might be prohibitive, effective and adequate dialyzer reuse can enable cost-effective and efficient dialysis similar to that offered by single-use dialyzers [23].

Dialyzer reuse is an option, but it must be done in accordance with established reprocessing protocols to guarantee the health and well-being of the patients. Dialyzer reprocessing units need stringent quality assurance checks to guarantee that all parts have been thoroughly cleaned and disinfected before use [24].

Making dialysis therapy more widely available for people with ESRD may be accomplished at a lower cost thanks to the creation of a dialyzer reprocessing device. To improve access to dialysis therapy in low-income countries, it is anticipated that the technology discussed in this article, in the form of the prototype shown here, would be used more extensively. To maintain patient safety and treatment effectiveness, however, quality assurance and standard reprocessing processes must be strictly adhered to at all times [25].

RECOMMENDATIONS

Many suggestions for enhancing the design and operation of the dialyzer reprocessing unit for patients with ESRD are offered in the discussion following the study's findings.

AADI (Association for the Advancement of Medical Instrumentation) guidelines for dialyzer reprocessing should always be followed first and foremost (AAAMI). All efforts should be made to strictly adhere to these guidelines for the prevention of contamination and infection during dialyzer reuse, which have been designed to guarantee the safety and effectiveness of this practise. In addition, the reprocessing unit should be tested and monitored often to make sure it is operating correctly and that the dialyzers are being thoroughly cleaned and disinfected [26].

Second, there's potential for using alternative energy sources to power the dialyzer reprocessing unit. This would be especially useful in low-income nations where access to energy is restricted, lowering the cost of dialysis therapy and making it more accessible to those in need. The low-pressure pump and other parts of the reprocessing unit might, for instance, run on solar power.

Finally, further studies are needed to determine the viability of dialyzer reuse in various clinical contexts and patient demographics. This would be useful for figuring out whether and how often a dialyzer may be used again, and whether or not it's acceptable for all people with ESRD. Dialyzer reprocessing units, supplies, and the risk of infection or other consequences should all be accounted for in studies that assess the cost-effectiveness of reused vs disposable dialyzers. Fourth, there has to be more of an emphasis on getting the word out to doctors and patients alike about the benefits of dialyzer reuse and the significance of adhering to correct reprocessing procedures. This might be achieved via several channels of communication, including instructional and outreach campaigns. Dialyzer reprocessing programmes should be developed and implemented with input from patient advocacy organisations and other stakeholders, and healthcare practitioners should be strongly encouraged to work with these groups [27].

Last but not least, it is vital to acknowledge the dialyzer reprocessing unit's potential as a tool for expanding access to dialysis therapy in developing nations. Patients with end-stage renal disease (ESRD) may benefit from lower treatment costs, more access to care, and better health outcomes if a reprocessing unit is implemented. Hence, collaborations with governments, NGOs, and other stakeholders are necessary to encourage the reprocessing unit's acceptance and deployment in such circumstances.

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