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Original Article

The efficacy of a wearable hemodialysis with tentative equipment in chronic renal failure

Sonay Oguz[1], Halil Fatih Asgun[1], Serkan Bakirdogen[2], Dilek Ulker Cakir[3]

[1]Departmenf of Cardiovascular Surgery, Academic Medical Center, Çanakkale Onsekiz Mart University, Çanakkale, Turkey; [2]Departmenf of Nephrology, Academic Medical Center, Çanakkale Onsekiz Mart University, Çanakkale, Turkey; [3]Departmenf of Clinic Biochemistry, Academic Medical Center, Çanakkale Onsekiz Mart University, Çanakkale, Turkey

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Abstract: Objective: The aim of this study was to find an effective and simple method by which outpatient hemodialysis can be performed using diffusion and ultrafiltration methods with different procedures on a model. Methods: A solution containing high-level urea and creatinine similar to the blood values of patients with chronic renal failure was used, with the expectation of clearing it as in hemodialysis using a model with the designed system. The product values at the beginning and end of the process were determined, and the cleaning rates were calculated. Results: The clearance rates obtained in the serum were 79.2% for urea and 93.7% for creatinine. Greater than 65% clearance rates were detected in all products except calcium and magnesium. Statistical significance was found in all products ($P < 0.05$) except magnesium ($P = 0.065$). Conclusions: Using this method, we achieved a clearance rate greater than the desired clearance rates (65%) in hemodialysis.

Keywords: Diffusion, renal failure, outpatient hemodialysis, ultrafiltration

Introduction

Chronic renal failure (CRF) is an important public health problem that has become a global health concern. CRF is defined as objective renal damage for at least 3 months or lowering the glomerular filtration rate below 60 ml/min/1.73 m^2 [1]. In previous studies, it has been reported that there is a marked increase in the incidence and prevalence of CRF [2, 3]. With the growing world population, an increasing number of end-stage renal disease (ESRD) patients can be also predicted. There are currently only 3 treatment options (hemodialysis [HD], peritoneal dialysis, and kidney transplantation) for renal replacement therapy to treat ESRD [4]. Although kidney transplants provide good results, it is not possible for every ESRD patient to undergo transplantation [5]. Patients who undergo HD are required to stay connected to a dialysis machine for 2 to 3 sessions for 4 to 6 hours per week. This process negatively affects the psychosocial status of the patients, causes loss of labor, and increases the cost [5]. Today, artificial kidney devices have not yet been reduced to appropriate sizes and they are not being used in routine procedures. HD is currently the preferred renal replacement therapy in many countries, although there is some variation by country [6]. During HD, owing to the patient's long connection to the dialysis machine, loss of labor, risk of infectious diseases, high cost, and increasing socioeconomic problems, HD can have negative impacts for both the patient and the country's economy because of increasing health expenses [4, 7, 8]. To counter these negatives, home HD has shown promise as a very positive development for patients and countries [9]. However, the patient must still remain connected to a machine in home dialysis systems. If HD could be performed as an outpatient with wearable equipment, it would improve the comfort and convenience for the patients. We designed a model experiment which procedures could achieve this purpose.

Figure 1. Parts of the model experiment. 1. ECS; 2. Roller pump; 3. Ultrafiltrator; 4. Ultrafiltration diffusion assembly (UDA); 5. Interconnections and pressure measurement system (5A. Premembrane pressure; 5B. Postmembrane pressure) 6. Ultrafiltrate waste collection container; 7. Heater.

Materials and methods

Parts of the model

Experimental circuit solution: In our model, an experimental circuit solution (ECS) equivalent to the blood value (high urea level) of a patient with CRF was designed to perform blood dialysis with the test system (**Figures 1** and **2**). Our model was designed to show the effectiveness of the procedure by comparing the initial blood values with the blood and ultrafiltrate values taken during and at the end of the process (complete blood count, urea, creatinine [Crea], sodium [Na], potassium [K], magnesium [Mg], calcium [Ca], and chloride [Cl]). To date, there is no description of a similar ECS in the literature. For this reason, based on our own calculations and measurements, we created an ECS mixture containing high urea and Crea values as would be seen in a patient with ESRD. When preparing the ECS, the volume was initially completed to a total of 7 liters using isotonic sodium chloride and the urine (1.5 L) of a patient without CRF. Hematocrit was adjusted to 30% using 2 units of whole blood and 8 units of erythrocyte suspension that were expired in the blood bank. Heparin was used at a dose of 300 u/liter for anticoagulation.

Pump function: The pump function used in the model was provided using roller pump assembly of a heart-lung machine (Terumo System1; Terumo Cardiovascular, Ann Arbor, MI). Lines measuring three-eighths to one-quarter were used as connection lines. We investigated the smallest size ultrafiltrators that can be fitted to the patient that are available on the market. The smallest found was the pediatric ultrafiltrator (FX paedhelixone highflux; Fresenius Medical Care, Bad Homburg, Germany), which was used in the model.

Heating system: A heating system was added to ensure that the experiment was performed at a temperature equivalent to body temperature (Glass Heater; Goldisgood Electrical, Guangxi, China).

Pressure monitors, flowmeter, and interconnections: A recirculation assembly was created by connecting the ECS, roller pump, and ultrafiltrator sequentially to each other with lines (**Figure 2**). The desired membrane pressures were achieved by the control of the pressure monitors located in front of (premembrane pressure monitor; **Figure 1**, 5A) and behind the ultrafiltrator (postmembrane pressure monitor; **Figure 1**, 5B) with the transition clamps over the ultrafiltrator lines (**Figure 2**). In addition, the ultrafiltrator flow was monitored by the flowmeter (Novaflow-s Ultrasonic; Novaflow Systems Inc., Ontorio, Canada).

Ultrafiltration diffusion assembly: The ultrasound diffusion assembly (UDA) apparatus consisted of 2500 cc serum bags placed between 3 plates. Two of the plates were movable, with the bottom plate remaining stationary. Serum bags were connected to the ultrafiltrate outlet

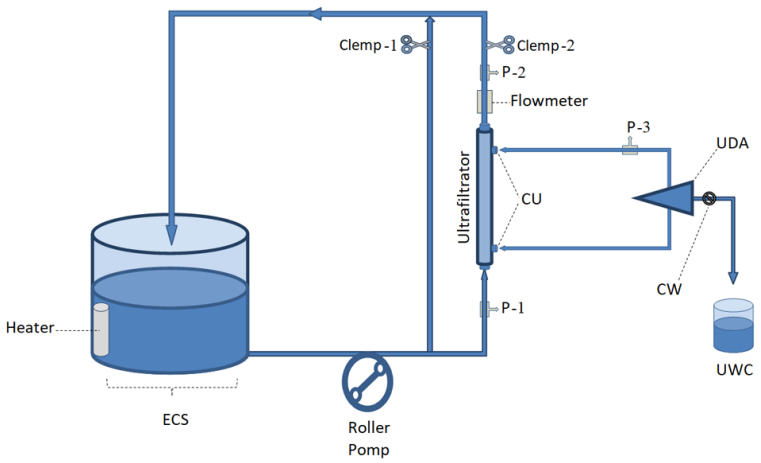

Figure 2. Simple schemaview of model; Clemp-1. Control of flow and pressure (premembrane) on the line; Clemp-2. Control of flow and pressure (postmembrane) on the line; CU. Connection point of ultrafiltrate on the ultrafiltrator; CW. Connection of UWC via the switch; ECS. Experimental circuit solution; Flowmeter. Measuring flow on the ultrafiltrator; P-1. Premembrane pressure monitor connection; P-2. Postmembrane pressure monitör connection; P-3. Ultrafiltrat pressure monitor connection; Roller pomp. Required pumping to ensure circulation flow; UDA. Ultrafiltration diffusion assembly; UWC. Ultrafiltrate waste container.

of the ultrafiltrator. In this way, the serum bags were filled with ultrafiltrate. As the serum bags were filled, the plates rose and the volume level could be seen from the scale. The top plate showed the volume level. The middle plate was placed to increase fluid motion (**Figure 3**).

As seen in **Figures 2** and **3**, the filtered ultrafiltrate was deposited in the UDA. The UDA was a closed system that allowed the filtration of ultrafiltrate at the desired fixed volume (**Figure 3**). In addition, the UDA apparatus allows increasing the diffusion and sending fluid back to the ECS via the ultrafiltrator.

As seen in **Figure 3A**, after the ultrafiltrate accumulated at constant volume, an increase in diffusion may occur by moving the middle plate and increasing the volume of the ultrafiltrator membrane contact. This movement was similar to a churning motion to increase the amount of ultrafiltrate that was in contact with the membrane surface of the ultrafiltrator. The aim of this assembly was to observe the blood filtration function and the resulting ultrafiltrate changes by forcing the limits of the ultrafiltrator.

Biochemical analysis

Na, K, and Cl were measured using the ion selective electrode method on a Cobas 6000 autoanalyzer (Roche Ltd, Nutley, USA). Ca, Mg, Crea, and urea measurements were made using the colorimetric method on a Cobas 6000 autoanalyzer 501 unit. The flow coefficient values of the tests were as follows: Na, 0.3%; K, 0.5%; Cl, 0.5%; Ca, 0.8%; Mg, 0.8%; Crea, 1.2%, and urea, 1%. In the biochemical analysis, 1-to-1 dilution with 40% polyethylene glycol 6000 was performed to prevent the hemolysis from affecting the results. The supernatant obtained was studied.

Statistical analysis

The study data were analyzed using the statistical software program SPSS (version 20.0; IBM Corp., Chicago, IL). The clearance ratios of all products (Urea, Crea, Na, K, Ca, Cl, Mg), percentages, means, standard deviations, medians, and minimum and maximum values were used in the presentation of the data. Analysis of variance (post hoc, Tukey method) was used as a parametric test according to the normal distribution compatibility test results. Statistical significance was accepted at a cutoff *P* value of less than 0.05. In addition, a urea reduction rate value of greater than 65%, which shows effective dialysis in hemodialysis [10], was accepted as a criterion of success in our study.

Stages of experiment

Four separate stages were planned in our experiment. In Stage 1, the membrane pressure value, where the highest density of ultrafiltrate fluid accumulated at the end of ultrafiltration in terms of urea and other waste materials, was determined (effective ultrafiltration membrane pressure). In the second stage, during the diffusion process, we attempted to determine the time in which the resulting ultrafiltrate urea value was equal to the ECS urea value (effective diffusion time). In Stage 3, the fluid was returned to the patient through the same ultrafiltrator membrane by creating reverse membrane pressure. This process is a technique that has not been used previously and could be described as the reverse use of

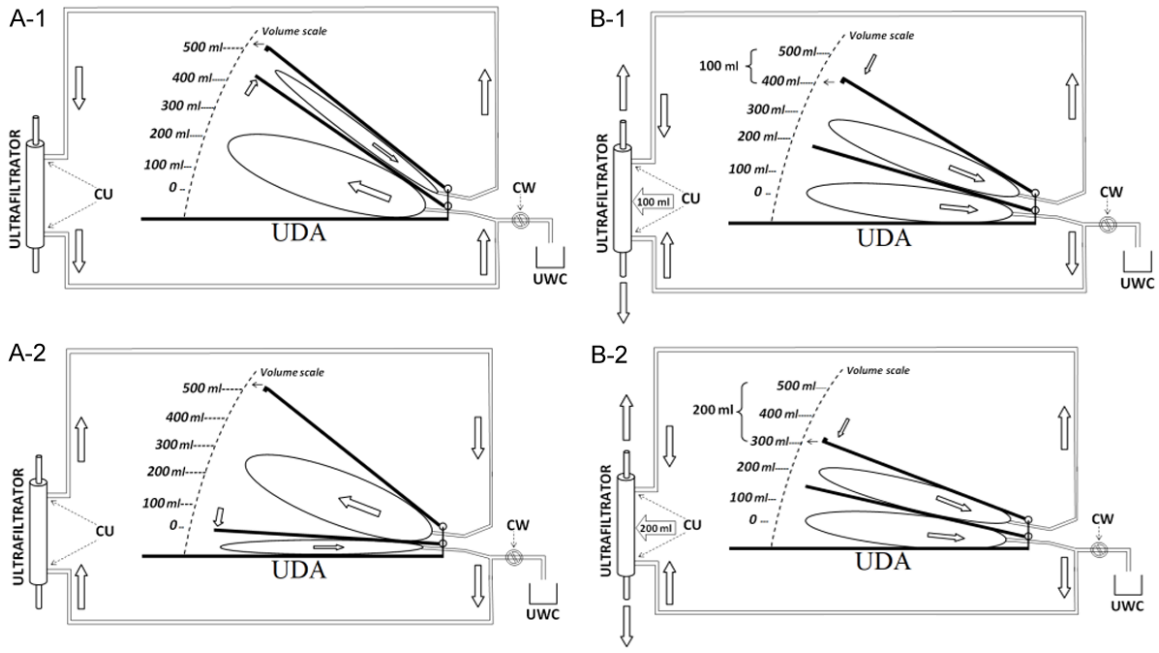

Figure 3. UDA and connections; For Increasing diffusion, middle plate is moved up (A-1), then moved down (A-2). Sending fluid (100 ml) back to the patient through the filter (B-1). Sending fluid (200 ml) back to the patient through the filter (B-2); CU. Connection point of ultrafiltrate on the ultrafiltrator; CW. Connection of UWC via the switch; UDA. Ultrafiltration diffusion assembly; UWC. Ultrafiltrate waste container.

the ultrafiltrator. Because the UDA is a closed system, by pressing the top plate downward, fluid pressure rises and pressure forms in the ultrafiltrator membrane reverse. In this way, fluid transition back to the patient occurs (**Figure 3B**). At this stage, the primary purpose was to send liquid with high water content back to the patient from the collected ultrafiltrate. As a result, after returning the ultrafiltrate with highwater content to the patient, a higher concentration of liquid was expected to remain in the UDA. This liquid could be accepted as waste, with higher urea and Crea content. In Stage 4, according to the data obtained in the previous stages, blood clearance rates were found with cycles by successively continuing the stages.

Results

Stage 1

Before starting the experiment, the first blood samples were taken from the prepared ECS and the initial values of the products were determined. The system was started by activating the roller pump with a flow of 2000 ml/min. Transmembrane pressure (TMP) was calculated using the formula = premembrane pressure + postmembrane pressure/2 [11]. The samples were taken separately from the ultrafiltrates (100 cc) obtained by creating 50, 100, 300, 400, and 600 mmHg TMP values with clamping. The ultrafiltrator flow was kept at 200 ml/min (±50 ml/min) using the flowmeter.

Stage 2

When the values obtained at the end of Stage 1 were examined, all TMP (50-600 mmHg) values were close to the initial blood values (**Table 1**), indicating that effective ultrafiltration membrane pressurecan be provided at all TMP values. Therefore, Stage 2 was started with a nonhigh TMP (100 mmHg) value that would not force the ultrafiltrator. Ultrafiltration of 500 cc was obtained by hemofiltration with a normal TMP value (100 mmHg) in the second stage. Acceleration of diffusion was attempted using the middle plate movements as described above (**Figure 3A**) for 60 minutes.

When the results of the samples taken from outset, and at 0, 15, 30, 45, and 60 minutes were examined separately (**Table 2**), the ultrafiltrate content was found to show approximately

Table 1. Data obtained in the first stage of the experiment

	UREA (mg/dl)	Crea (mg/dl)	Na (meq/L)	K (meq/L)	Ca (mg/dl)	Cl (meq/L)	Mg (mg/dl)
ECS (outset)	204.4	13.78	134	13.43	2.51	124.7	1.58
50 mmHg (ultrafiltrate)	201.3	14.58	136	13.21	2.31	126.3	1.66
100 mmHg	200	14.26	136	13.2	2.24	126.3	1.63
300 mmHg	196.4	14.53	135	13.06	2.23	125.2	1.62
400 mmHg	199.1	14.66	138	13.13	2.26	128	1.53
600 mmHg	205.8	14.23	137	13.16	2.18	127.4	1.57

Table 2. Ultrafiltrate values with diffusion time in stage 2

	UREA (mg/dl)	Crea (mg/dl)	Na (meq/L)	K (meq/L)	Ca (mg/dl)	Cl (meq/L)	Mg (mg/dl)
ECS (outset)	204.4	13.78	134	13.43	2.51	124.7	1.58
0 Minute	193.2	14.57	135	13.53	2.22	126.1	1.63
15 Minute	202.6	14.75	136	13.55	2.32	125.5	1.64
30 Minute	209.6	14.62	136	13.55	2.31	125.4	1.62
45 Minute	205.4	14.31	136	13.5	2.31	125.6	1.65
60 Minute	203.9	14.76	136	13.55	2.3	125.9	1.62

Table 3. Results obtained under reverse membrane pressure in stage 3

	UREA (mg/dl)	Crea (mg/dl)	Na (meq/L)	K (meq/L)	Ca (mg/dl)	Cl (meq/L)	Mg (mg/dl)
ECS	199.5	14.3	133	13.46	2.57	123.7	1.62
UF	196.3	14.24	137	13.65	2.28	126.3	1.63
-50 mmHg	198.2	14.31	136	13.63	2.27	125.2	1.66
-400 mmHg	196.4	14.53	135	13.06	2.23	125.2	1.62

the same values with the process applied. Because there was no difference in diffusion times, the effective diffusion time was appointed as 0 second.

Stage 3

The roller pump was stopped after obtaining 500 cc ultrafiltrate fluids with 100 mmHg TMP. During the diffusion process, the reverse membrane pressure described above was simultaneously generated. For this, it was seen that the desired pressure from the monitor was provided by pressing the upper plate with by hand. At the same time, fluid transition from the ultrafiltrator back to the patient was followed visibly.

The results obtained from 100 cc ultrafiltrate, which remained after sending 400 cc back through the ultrafiltrator membrane to the patient, are seen in **Table 3**. The samples were taken by applying the process at both low (-50 mmHg) TMP and high (-400 mmHg) TMP. No significant change in pressure difference was observed while the fluid was returned to the patient by reverse membrane pressure. This result also demonstrated that the ultrafiltrator works in the opposite direction and provides a high product transition. Thus, the result of Stage 3 indicated a reverse membrane pressure of 0 mmHg and the return of 0 ml volume to the patient.

Stage 4

According to the data obtained from Stages 1, 2, and 3, the fourth stage was conducted. As there was no concentration change in TMP, ultrafiltrator perfusion was achieved with a pressure of 200 mmHg. When 500 cc of ultrafiltrate was collected, this volume was transferred to the waste bag, and 500 cc of clean drinking water was added to the ESC. This process was considered as a “cycle” and was repeated 16 times. The mean cycle time was 15.6 minutes (±2.6 min). Samples (urea, Crea, Na, K, Ca, Cl, and Mg) were taken from both the ultrafiltrate and the ECS in the 1st, 6th, 11th, and 16th cycles.

Table 4. Clearance Ratios of products in stages

	Urea (%)	Crea (%)	Na (%)	K (%)	Ca (%)	Cl (%)	Mg (%)
Stage-1	0.68	6.38	2.98	-1.63	-7.9	2.64	3.1
Stage-2	2.5	7.1	1.4	0.8	-7.5	1.1	5
Stage-3	-0.6	2	2.2	1.2	-11.2	2.1	2.4
Stage-4	79.2	93.7	83.1	77.8	-47.5	80	5.8

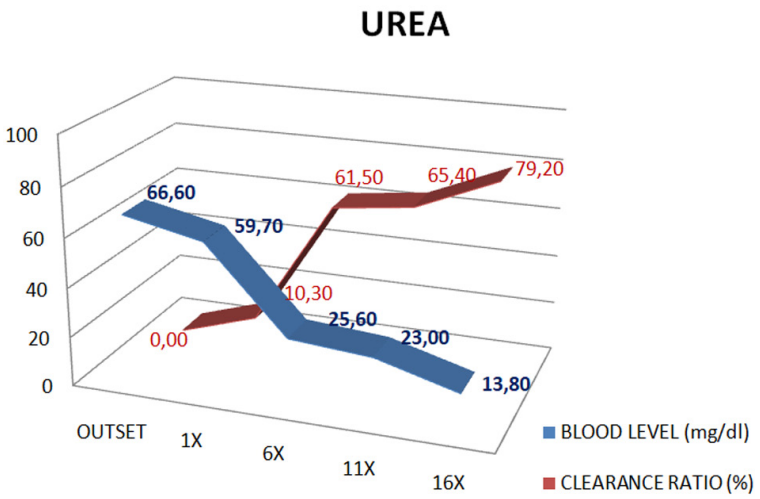

Figure 4. ECS urea level and clearance rate throughout the cycles; Blood level. Urea level throughout the cycles in the ECS; Clearance ratio. Cleaning ratio of urea throughout the cycles in the ECS.

Biochemical analysis results

The data obtained in Stage 1, namely ECS (outset), 50 mmHg, 100 mmHg, 300 mmHg, 400 mmHg, and 600 mmHg (ultrafiltrate), are shown in **Table 1**. The results of Stage 2 are shown in **Table 2**. Results obtained under reverse membrane pressure in Stage 3 are demonstrated in **Table 3**. The clearance rates obtained in all stages are shown in **Table 4**. It was observed that the clearance rates obtained in Stages 1, 2, and 3 were below the ideal urea reduction rate achieved by hemodialysis. The Stage 4 clearance rate was greater than 65%, except for Ca and Mg (**Figure 4**).

Statistical analysis results

A significant difference between groups was determined in all products ($P < 0.05$) except Mg ($P = 0.065$). The mean, median, standard deviation, maximum, minimum, and P values of all products according to the clearance ratios obtained at all stages are listed in **Table 5**.

When the cleaning rates of the products are compared, there was a statistically significant difference between the 4 groups in urea, Crea, Na, K, Ca, and Cl ($P < 0.05$). For these products, there was no statistically significant difference between the 1st and 2nd groups ($P > 0.05$), 1st and 3rd groups ($P > 0.05$), and 2nd and 3rd group ($P > 0.05$). There was a statistically significant difference between the 1st and 4th groups ($P = 0.001$), 2nd and 4th groups ($P = 0.001$), and 3rd and 4th groups ($P = 0.003$).

Discussion

The principles of ultrafiltration and diffusion form the basis of the HD process performed for blood purification [12-14]. Currently, large devices and large amounts of purified water are used in HD processes [15]. In addition, HD results in an increased risk of infection and loss of labor among the patients who are connected to the dialysis machine for long periods. To remain connected to the hemodialysis machine and immobilized for hours during dialysis is also very uncomfortable for patients and negatively affects their psychosocial status. Along with the increasing world population and patient population, it is expected that there will also be an increasing burden for health expenditures and national economies.

There are currently only three options available as treatment options for patients with ESRD, namely peritoneal dialysis, HD, and renal transplantation. The most frequently performed renal replacement therapy around the world is HD [11].

To provide blood purification by ultrafiltration and diffusion methods that form the basis of HD may be an option worth considering. We created a model with the help of an apparatus designed to show whether the blood purification process could be achieved using a method other than today's techniques. The aim

Table 5. The clearance ratios obtained in stages and statistical results

V	Stage-1 (n = 5)	Stage-2 (n = 5)	Stage-3 (n = 3)	Stage-4 (n = 4)	P
	Median (Min-Max)	Median (Min-Max)	Median (Min-Max)	Median (Min-Max)	
Urea	-2.1 (-4/1)	-0.2 (-5/3)	-0.6 (-2.0)	-63.5 (-79/-10)	0.0002
Crea	5.4 (3.2/6.4)	6 (3.8/7.1)	0.1 (-0.1/2)	-68.7 (-93/-13.8)	0.0001
Na	1.5 (0.7/3.0)	1.4 (0.7/1.4)	2.2 (-1.4/3.0)	-58.8 (-83.1/-10.2)	0.0004
K	-2.1 (-2.7/-1.6)	0.8 (0.5/0.8)	1.2 (-2.9/1.4)	-42.6 (-77/-5)	0.0052
Ca	-10.7 (-13.1/-7.9)	0.8 (0.5/0.8)	0.1 (-0.1/2)	37.1 (2.9/63.3)	0.0003
Cl	1.2 (0.4/2.6)	0.7 (0.5/1.1)	1.2 (1.2/2.1)	-55.5 (-80/-10)	0.0005
Mg	2.5 (-3.1/5.0)	3.8 (3.1/5.0)	1 (0.6/2.4)	4.8 (2.9/9.8)	0.0654

SD: Standart Deviation, Min: Minimum, Max: Maximum, P: ANOVA test, V: Variables.

of this experiment was to detect changes in different membrane pressures by using a small ultrafiltrator that could be attached to the patient, to observe diffusion changes with time, and to show whether appropriate waste concentration can be generated by sending liquid back to the patient through the same filter using reverse membrane pressure. This experiment was intended to show that HD can also be performed with simple equipment that can be attached to the patient and still achieve the required results. The movement of molecules is based on the principles of membrane physiology. Low molecular weight substances show a rapid transition with faster membrane transport. In addition, the transition changes according to gradient and membrane pressure. These effects can be used to separate substances to be protected and discarded. After obtaining as high product concentration as possible (especially of urea and Crea) in the ultrafiltrate accumulation, it is possible to return a high water content back to the patient via the ultrafiltrator. In this way, waste products, such as urea and Crea, can be deposited in the ultrafiltrate. In our experiment, we aimed to determine how much of fluid transition could be achieved by membrane pressure changes.

Concentration changes in ultrafiltrate accumulated by low and high membrane pressure were observed in the first stage. It was found that there was no significant change for urea, Crea, and other products in the ultrafiltrate that accumulated under low and high pressures (**Table 1**). In the second stage, the accumulated ultrafiltrate was subjected to 1 hour of diffusion. There was no apparent change in ultrafiltrate accumulated during the diffusion process, especially for urea, Crea, and other solutes (**Table 2**). In the third stage, we observed that whether there was a change in the product concentration in the remaining ultrafiltrate by returning the ultrafiltrate liquid back to the patient by creating reverse membrane pressures (**Table 3**). In this stage, there was also no significant concentration change in other solutes, especially urea.

In these stages, the high flux ultrafiltrator used was found to have a high transition property, which is a known feature of high flux filters [16]. Although the transition speeds of low flux filters were lower, they are not sized small enough to attach to the patient. Also, because there were previous studies reporting on the superiority of high flux filters [17-19], the new generation of high flux filters was used in the model. The results could be different when using a low flux ultrafiltator.

The ultrafiltrator was started with a 200 ml/minute flow rate in the range of 20-50 mmHg TMP, and 100 cc of ultrafiltrate accumulated at 4.25 minutes. It was able to filter 100 cc of ultrafiltrate at a pressure of 200 mmHg at 3 minutes and at a pressure of 600 mmHg at 2.15 minutes. These values were obtained by creating premembrane pressure. When the postmembrane pressure was created, it was observed that, as the transmembrane pressure increased, the filter decreased when it was expected to perform faster filtration. This result was owing to a decreased volume of blood flow through the filter. When applying negative pressure to the ultrafiltrator (ultrafiltrate side), it was seen that the ultrafiltrator filtration process stopped at values above -200 mmHg pressure. Fibrillar structures in the inner part of the ultrafiltrator were seen to move outward

Table 6. Used liquid product concentration in the experiment

	UREA (mg/dl)	Crea (mg/dl)	Na (meq/L)	K (meq/L)	Ca (mg/dl)	Cl (meq/L)	Mg (mg/dl)
ECS (Outset)	66.6	5.42	25.66	107	2.02	97.5	1.02
ECS (Last)	13.8	0.34	5.66	18	2.98	19.4	0.92
Drinking Water	0.1	0.29	0.1	3	3.99	2.1	1.05

and a small amount of ultrafiltrate with hemolysis was filtered. When the same process was conducted at a pressure value of -50 mmHg, the filtration process was observed to be the same. This was interpreted as high negative pressure occluding the blood-shaped elements by covering the membrane pores within the ultrafiltrator. The filtration process may have stopped when the pores did not remain open. The hemolysis image also supported this. We observed that the ultrafiltrator was able to provide filtration with low membrane pressure (50 mmHg) and a low flow rate (200 ml/min) very easily and in a short time (100 ml/4.25 min). The resulting ultrafiltrate was found to be very close to the concentration of urea, Crea, and other solutes in the ECS. These values demonstrated that there was no need for diffusion in the model.

We designed our experiment to add drinking water to the ECS in the final stage. In this way, we believed we would obtain a realistic observation of the results according to the liquid that a patient with CRF would drink from the mouth.

The final stage of the experiment was started with a premembrane pressure of 200 mmHg. After 500 cc of ultrafiltrate output, 500 cc of liquid (drinking water) was added to the ECS. This process was described as a cycle. The cycles were continued in the same way by taking samples from the ECS and ultrafiltrate. At the end of the 6th, 11th, and 16th cycles, samples were taken from ECS and ultrafiltrate. The reason for planning 16 cycles was to compare the process as performed during the day with an active time of 16 hours plus 1 hour for each cycle, assuming 8 hours of a day for sleep. The duration of all cycles were recorded. The mean cycle time was 15.6 minutes (±2.6 min), and all 16 cycles were completed in a total period of 4.6 hours.

The urea concentration in the ECS decreased as the cycles continued. In our experiment, the clearance rates of Crea, K, Na, and Cl yielded similar results (**Table 4**). Another problem among CRF patients is K elevation [20]. In our experiment, the K excretion rate was very high.

An important point here is the observation of different changes in Ca and Mg while other products (urea, Crea, Na, K, Cl) were reduced. This was because of the addition drinking water added to the 500 cc ECS rather than the 500 cc ultrafiltrate taken in each cycle.

The Ca level in the ECS at the beginning was 2.02 mg/dl and was seen to increase to 2.98 mg/dl at the end of the experiment. This is entirely related to the fact that the amount of Ca in the fluid added to the ECS was 3.99 mg/dl. The Mg content was also close to other values (1.05-1.02 mg/dl), and a result close to these values was obtained at the end of the experiment (0.92 mg/dl). This predictable situation generates an increase according to the concentration of solute in the fluid added to the ECS (**Table 6**). This was expected to continue until it was equal to the concentration in the liquid added.

Statistical significance were determined in all products ($P < 0.05$) except Mg ($P = 0.065$) (**Table 5**). The experiment clearly resulted in a significant decrease in urea level, which was the main target, and the clearance rate was 79.2%. However, Na, K, and Cl levels were found to be decreased significantly. This difference can lead to serious health problems (i.e., hyponatremia, hypopotassemia, metabolic alkalosis) in HD patients. This does not seem to be an acceptable value.

The biggest result of our experience with these values is that with diffusion and reverse membrane pressure, there was no need for separate stages to send fluid back to the patient, which require additional time. In addition, the results of ultrafiltration can be achieved in a fast and efficient way. We found the results in our model using a highflux ultrafiltator, but

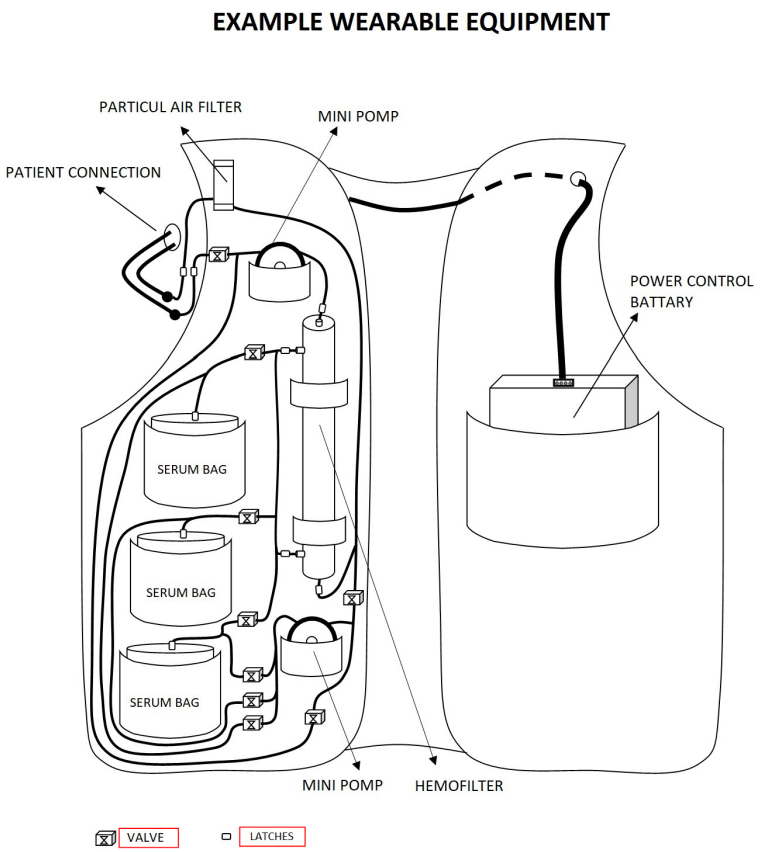

Figure 5. Example wearable equipment.

results may be different using a lowflux ultrafiltator.

A very important point is that the fluid given to the patient should not disrupt the balance of the body's electrolyte and mixtures of glucose, K, bicarbonate, and acetate should be provided at an individual rate for each patient according to the patient's characteristics.

In our experiment, we were able to clean the blood from urea and Crea. However, this is not the only subject to be achieved for HD. Many other issues such as blood components, intravascular and extravascular, and cellular interactions need to be elucidated. However, we believe this is a good start.

Conclusions

We attempted to determine a method for outpatient HD using a basic alternative procedure. In our experiment, we managed to clean the blood from urea and Crea. This process can be done by hemofiltration with only a mechanism based on a simple mini pump and ultrafiltrator (example schema; **Figure 5**), but this method must be compared with other advanced studies to evaluate other blood elements and their effects on the body. We believe that the data obtained from our experiment will guide other experimental and clinical studies that will form the basis of outpatient HD method.

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Disclosure of conflict of interest

None.

Address correspondence to: Dr. Sonay Oguz, Department of Cardiovascular Surgery, Çanakkale Onsekiz Mart University, Barbaros Street Terzioglu Campus B Block No. 4 Canakkale 17100, Turkey. Tel: +90 286 263 59 50; Fax: +90 286 263 59 56; E-mail: soguz@comu.edu.tr

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