Development of Remote Controllable Pulsatile Hemofiltration System

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Abstract— **Purpose of this paper is developing a small and light hemofiltration system for chronic renal failure patients with internet interface to expert group to alternate hospitalized hemofiltration system, therefore, privacy and economic efficiency can be satisfied.**

This system is composed with a blood pump, replacement pump and effluent pump which implements hemofiltration machine. To control each pump, motor controllers with MCU (ATMEGA8535) were attached on pumps, respectively and as an integrated controller, master controller(ARM920T) was fabricated to control motor controllers, sensors, LCD, touch screen and interface with internet. On site of expert group, every patient data and operational information during hemofiltration are displayed and expert sends orders through web server. An extra corporeal blood pump is designed as a pulsatile pump so that in condition with equal transmembrane pressure (TMP), the efficiency of the ultra filtration (UF) is high and destruction of red cells caused by long extra blood circulation is reduced. Blood leakage detector, pre-filter pressure sensor, veinous line pressure sensor, bubble detector and aterial line pressure sensor is attached to protect patients from abnormal operations.

In vitro test, every sensor for abnormal operations works properly with visual and auditory senses, if needed, pumps are stopped.

In vivo test, I performed continuous venovenous hemofiltration (CVVH) treatment using the pulsatile hemofiltration system to verify if this system can carry out hemofiltration or not. The total values of URR of BUN and CrRR were 24.7% and 25.34% respectively which demonstrate this system operates hemofiltration well.

I. Introduction

As number of acute renal failure (ARF) and chronic renal failure (CRF) patients are increasing every year, we need to cope with increment of medical device and human resource. There are million patients of renal failure in the world and are increasing rate of 6% which will cause lack of caring system.

In addition, hospitalized renal failure patients are suffering from anxiety, depression, reduced physical abilities and frequent sexual dysfunctions and privacy and economic efficiency is not satisfied. Moreover, their family is facing strong social restriction, therefore, quality of life is very poor.[1]

If patients can be treated at home with remote controlled caring machine by expert group, they will have better opportunity for rehabilitance, employment and education, and their quality of life will increase. Due to USRD, in case of self-care hemodialysis, modality is 42% than established treatment.[2 3]

Hemofialysis system requires 170L of pure water per treatment, there will need additional system to produce pure water and this will cause increase weight, size and price. For hemofiltration system, it needs only 2~4L of replacement solution. The One[TM] (Commercial hemofiltration machine) of NxStage showed replacement capable of ß2-microglubulin is 0.75 rather than 0.58 of hemodialysis machine.[4]

These days, internet is well broaden whole the world and computerizing system is well developed. Therefore, with construction of network and remote controllable interface, home care hemofiltration will be realized.

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II. Material & Method

Pump system

As this system is hemofiltration system, it is composed with 3 pumps, blood pump, replacement fluid pump and effluent fluid pump. Blood pump is for circulating blood out of and into the body. It is designed for producing pulsatile flow to reduce red cell-destruction and enhance ultra filtration (UF) efficiency. [6 7 8](Fig.1-a) Replacement fluid pump delivers replacement fluid to the body and effluent fluid pump draws UF fluid out of dialyzer. They are designed as roller pump system. (Fig1-b,c)

Control system

Each pump is controlled by motor controller which is established with ATMEGA8535 and motor controller is controlled by ARM9. TCP/IP internet interface, touch screen and united sensor controller is attached on ARM9.(Fig.2)

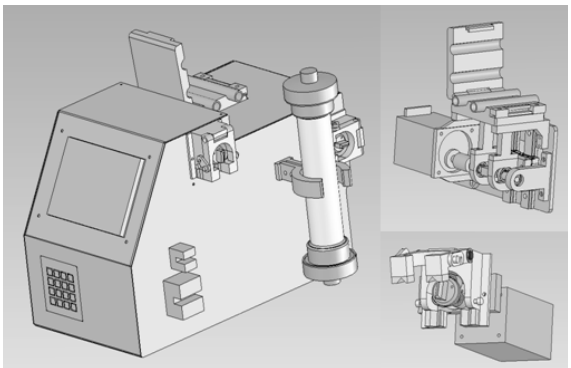

Figure1. a) Portable pulsatile hemofiltration machine with dialyzer. b) Blood pump for pulsatile flow. c) replacement and effluent fluid pump.

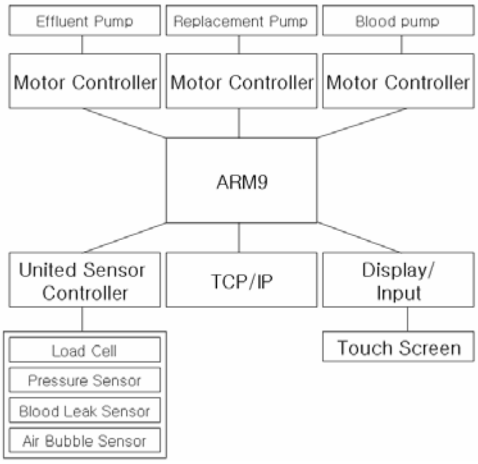

Figure 2. Block diagram of control system.ARM920T as a main controller and ATMEGA8584 as motor controllers.

Sensor controller contains loadcell, pressure sensor, blood leak sensor and air bubble sensor. Loadcell measures replacement fluid weight and effluent fluid weight to determine replacement fluid pump and effluent fluid pump speed. Pressure sensors are attached on pre-filter and veinous line. Blood leak sensor detects blood in effluent fluid and air bubble sensor detects bubble via blood line. These sensors are for protect patients from abnormal operations and they work with visual and auditory sense.

Data transmission

Between CPUs, data was transmitted with serial data line and formatted a packet containing two start bit and two end bit to identify which CPU transmits the signal. Data packet from motor controller to ARM920T contains transmission start signal, motor address, motor speed, received motor speed value, alarms of over loaded, high and low delivered power, transmission end signal and transmission success signal. Each CPU is programmed to detect miss transmitted data, therefore, if error happened, receiving CPU orders to send data again.

Remote control

Hemofiltration system transmits patients' health record, sensor information, pump speed to expert group via internet. Therefore, computer on expert group shows state of hemofiltration treatment, and expert group can change pump speed for safe treatment. For first connection between hemofiltration machine and expert group computer, computer request for connection and machine transmits JAVA applet to make TCP socket interface. Then, computer requests machine for treatment data periodically. After treatment, computer sends disconnect signal to let the machine go into stand by mode. (Fig.3)

In vitro test

Safety and capability of the system can be verified by checking each sensor works correctly and performance test of each pump. 0.4mL blood per 1L tap water was measured for blood leakage detector and bubble on blood line was induced for air bubble detector.

Each pump was drove with minimum to maximum speed step by step and out flow was measured to know pump capability and performance.

In vivo test

In vivo test was performed with a canine of 35kg. Renal arterial tube was vasolgated to dysfunction the kidney. Continuous venovenous hemofiltration (CVVH) therapy was performed to decrease high level of blood urea nitrogen (BUN) and creatinine to normal level. Gambro hemofilter 6S was used for dialyzer and 5kg of Hemosol B0 was used for replacement fluid.

For initial part, pre-dilution was applied with 100ml/min blood flow speed and post-dilution was applied with 125ml/min for latter part. As treatment started, blood was gathered for test every hour.

In vivo test was performed for 5 days to see if this system has tenacity or not.(Fig.4)

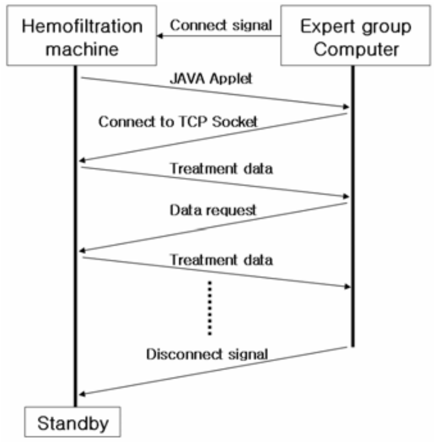

Figure 3. Interface between hemofiltration machine and computer of expert group.

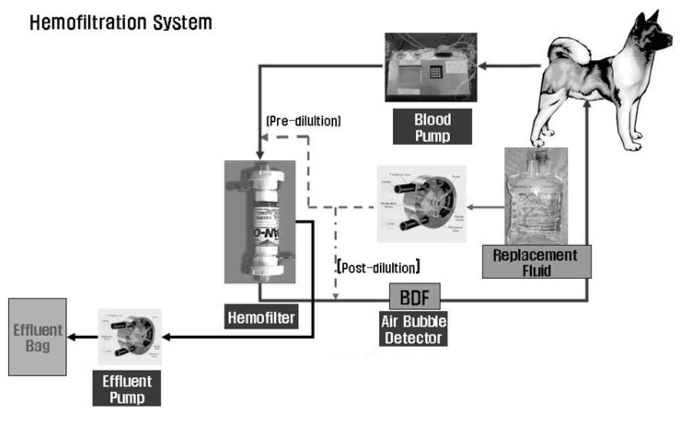

Figure 4. In vivo test circuit with Gambro hemofilter 6S and 5kg hemosol B0.

III. Result

Remote control

State information of the system was showed on expert group computer with 2.5sec delay and responds to received orders from expert group with 3.2sec delay. Transmitted information was correct between hemofiltration system and expert group computer and there was no missed value or errors during *in vitro* and *in vivo*. Machine to computer delay is affected by various parameters like delay IDE initial order of Windows^{TM}, distance between machine and computer and firewall etc.

In vitro test

With 0.4mL blood per 1L tap water, blood leakage detector detected as well as bubble detector detected air in the blood line. As soon as detectors detected blood and bubble, alarming sounded and warning message was displayed on machine LCD and computer monitor.

For blood pump, input range was established 0~255 which can be described by one byte. With maximum driving pump speed, flow volume was 398ml/min and effluent and replacement fluid pump flow volume was 164ml/min.

Input value verse actual pump speed showed almost linear gradient which means motor was controlled pertinently. (Fig. 5,6)

In vivo test

Every electrolyte (Ca, Cl, K, Na) was in normal range and ß2M and creatinine started to drop off as hemofiltration treatment started and after 200~280 minutes level of ß2M and creatinine decreased into normal level. Kt/V was 0.39 which shows this system treats permanently.(Fig. 7-11)

In addition, total values of URR of BUN and CrRR were

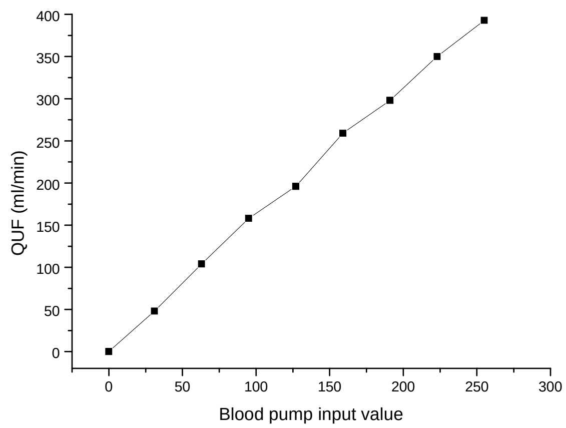

Figure 5. Blood pump input value versus fluid volume.

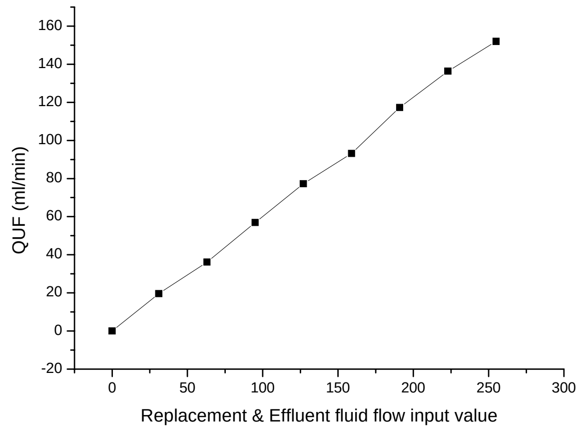

Figure 6. Blood pump input value versus fluid volume.

24.7% and 25.34% respectively.

After 5 days, a canine died because catheter side hole was locked due to clotting.

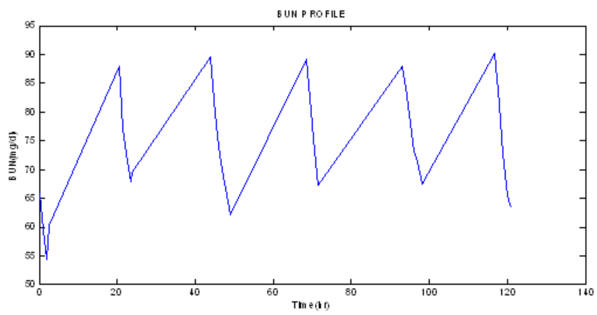

Figure 7. Time versus BUN changes. BUN decreased as treatment was performed.

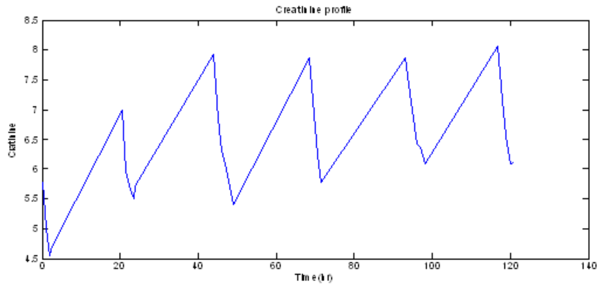

Figure 8. Time versus creatinine. Creatinine decreases as treatment was performed.

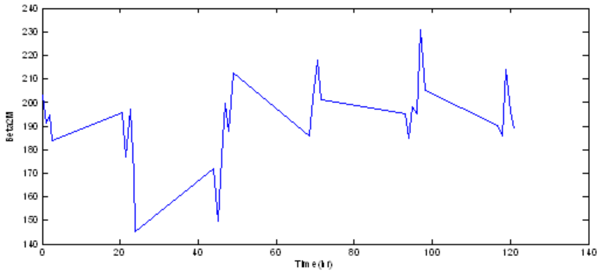

Figure 9. Time versus ß2M.

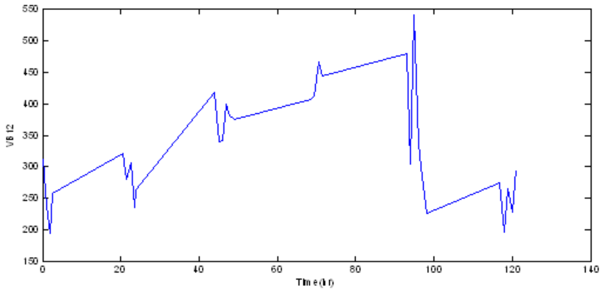

Figure 10. Time versus VB12

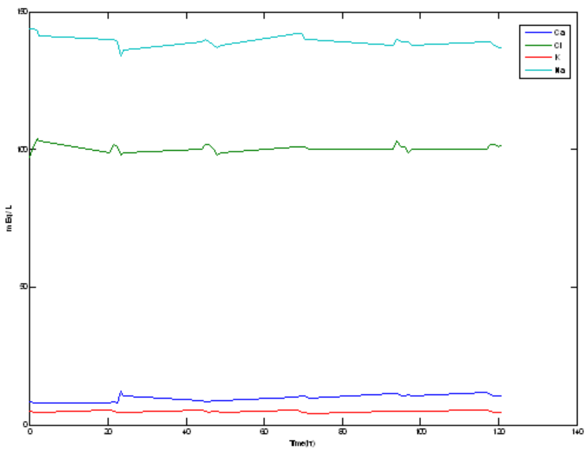

Figure 11. Time veres electrolyde.

IV. DISCUSSION

The goal of this study is developing a portable and remote controllable hemofiltration machine to enhance quality of life for renal failure patients and cope with lack of nursing system and human resource. As internet is well broaden and computing system is well developed, interface between hemofiltration machine and expert group is well established without no error or transmission failure. However, the performance test *in vivo*, it takes from 200min to 280min per day to accomplish acceptable BUN and ß2M concentration although electrolyte and Kt/V sustain acceptable level. This is caused by insufficient blood flow. To accomplish effective treatment, at least 83.3ml/min of UF volume is needed, however, with 100ml/min of blood flow, it couldn't be achieved. In addition, if pre-pump flow rate is increased, UF volume could increased, though body wastes is not ultra filtrated. Therefore, system with low pre-dilution and high efficiency is needed.

The canine didn't drink water during experiment period and caused faster BUN increase than expected. If the canine ingested 500ml of water each day, average concentration of BUN and creatinine would be low.

The cause of death of the canine was blood access method. To sustain survival, iuglar access was used rather than femoral access. For iuglar access, it is hard to secure blood flow volume and it caused clotting on catheter which caused lack of blood flow.

Judging from these results, as there were no problem remote control system and interface, to accomplish home hemofiltration for renal failure patients, more investigation of clinical method for stable blood access and effective body waste removal system.

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