A Proposed Peritoneal-Based Wearable Artificial Kidney

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Ideally, an artificial kidney should simulate the normal kidney in providing continuous metabolic control, removal of toxins, and unrestricted patient freedom. Of the dialysis procedures available, continuous ambulatory peritoneal dialysis (CAPD) comes the closest to this ideal but provides inadequate dialysis and fails to remove protein-bound toxins.

A continuous, wearable, peritoneal-based artificial kidney is proposed in which the spent peritoneal dialysate is regenerated using a REDY sorbent cartridge one-tenth the size of the present cartridge, with the urease chemically bound to an inert support to eliminate the possibility of its displacement by protein in the spent dialysate. To simplify the flow path and to increase clearance, the dialysate flow will be through the peritoneal cavity using a dual lumen catheter instead of the traditional in/outflow through a single catheter. At a flow rate of 4 L/hour through the peritoneal cavity, of which 2 L/hour will pass through the sorbent cartridge, it is estimated that the weekly Kt/V will be 6.5 and the creatinine clearance will be 250 L. In addition, any protein in the spent peritoneal dialysate will be stripped of toxins by the sorbents and returned to the patient, thereby minimizing protein loss. The only disposables will be the sorbent cartridge and infusate, which will be changed every 8 hours.

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Key words

Wearable artificial kidney, peritoneal dialysis, REDY Sorbent System

Introduction

An ideal artificial kidney should simulate the native kidneys in providing continuous metabolic control, eliminating protein-bound toxins, and allowing unrestricted patient freedom. Hemodialysis and automated peritoneal dialysis provide see-saw, intermittent metabolic control, fail to remove protein-bound toxins, and restrict the patient's freedom. While continuous ambulatory peritoneal dialysis (CAPD) provides a more stable metabolic control and more patient freedom, it also fails to remove protein-bound toxins. In addition, it provides inadequate dialysis for many anuric patients. Increasing the dialysis dose is limited to increasing the volume of each exchange and/or increasing the number of exchanges.

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Previous attempts to develop a wearable artificial kidney

A wearable artificial kidney based on hemofiltration and regeneration of the hemofiltrate with a miniature REDY (Sorb Technology Inc., Oklahoma City, OK, U.S.A.) sorbent cartridge provided continuous metabolic control and unrestricted patient freedom, but failed because of clotting in the hemofilter after a few days [1]. The proposed wearable artificial kidney based upon PD may eliminate the clotting problem; in addition, regeneration and reinfusion of the protein lost in the spent dialysate can result in the removal of protein-bound toxins.

Blumenkrantz *et al.* [2] were interested in developing a peritoneal-based, wearable kidney. Their approach was to first develop a nonwearable regenerative system for intermittent PD using the REDY sorbent cartridge. The cartridge was modified by removing the urease and sterilizing the sorbent cartridge by gamma rays. The urease, as a filter-sterilized, nonpyogenic solution, was added to the cartridge at the start of dialysis. Many patients were treated by this system, and one patient was maintained for 2 months. In anticipation of redesigning the system for a wearable kidney, spent fluid from a CAPD patient was passed through the cartridge. Unfortunately, the protein in the spent fluid displaced the urease in the cartridge, resulting in the presence of urease and ammonia in the regenerated fluid. Further investigation was discontinued.

In view of these results, we decided to separate the spent dialysate into protein and ultrafiltrate fractions by passing it through a hemofilter. We demonstrated that the ultrafiltrate fraction could be regenerated with a sorbent cartridge and filter sterilized [3]. We have also demonstrated that the protein fraction can be regenerated using the sorbents in a REDY cartridge. The regenerated protein retained the ability to bind calcium [4], aluminum [5], and various drugs [6].

In the present REDY sorbent cartridge the urease is adsorbed onto alumina. By chemically bonding urease to an inert support, displacement by other proteins can be prevented, and the alumina eliminated. Thereby, it will be possible to regenerate the spent dialysate without separating out the protein. This eliminates the need for a hemofilter. This change, combined with flow-through PD described below, simplifies the fluid path of the proposed wearable artificial kidney.

Flow-through PD

In traditional PD the dialysate is instilled into the peritoneal cavity, allowed to dwell for a given time, and then drained. Flow through PD, in which dialysate flows continuously into the peritoneal cavity through one catheter and out through another catheter (or a dual catheter), results in a urea clearance two to three times the traditional inflow/outflow PD [7].

Proposed wearable artificial kidney

The fluid circuit is shown in Fig 1. The peritoneal cavity is filled with 1 L of standard PD solution. The dialysate is then pumped out of the peritoneal cavity at a flow rate of 4 L/hour through one side of a dual lumen catheter with 2 L/hour of the flow being recirculated back into the peritoneal cavity through the other catheter lumen, while the other 2 L/hour flow is pumped into a sorbent cartridge. The sorbent cartridge will differ from the present REDY cartridge in that it will be one-tenth the size, gamma ray-sterilized, contain purified urease bound chemically to an inert support, and have fibrin and particulate filters. As with the present REDY system, the urea in the spent dialysate will be converted to ammonium carbonate by the urease. The ammonium ion will be exchanged for sodium and hydrogen ions in the zirconium phosphate layer, and the hydrogen ions will convert the carbonate to bicarbonate. Calcium, magnesium, and potassium will be exchanged for sodium in the zirconium phosphate layer. Phosphate and aluminum will be exchanged for acetate in the hydrated zirconium oxide layer. Creatinine, uric acid, and other organic compounds will be removed by the activated carbon layer.

A sterile infusate containing concentrated glucose and calcium and magnesium acetates will be added to the effluent of the cartridge to replace the electrolytes removed by the cartridge and the glucose metabolized by the patient. The glucose concentration of the infusate will be adjusted as necessary to control ultrafiltration. Excess fluid will be drained, just before the sorbent cartridge, into a leg bag to maintain a constant fluid volume in the fluid circuit. The leg bag will be emptied periodically.

Any toxins bound to the protein in the spent peritoneal dialysate will be removed by ionic exchange in the zirconium layers or by adsorption to the activated carbon. The only protein loss will be the small amount in the excess fluid discarded.

The regenerated dialysate will then be returned to the patient. Every 8 hours the cartridge and infusate will be replaced. The patients will measure their weight and select an infusate with the glucose concentration required for the desired amount of ultrafiltration.

There will be no need to replace the dialysate or the tubing set. Any lactate in the initial dialysate will be metabolized by the patient, so that the dialysate will be a bicarbonate dialysate and the patient's acidosis will be corrected by the bicarbonate formed from the patient's urea as with the present REDY system.

Three pumps will be required to recirculate the dialysate, pump fluid into the sorbent cartridge, and add infusate to the cartridge effluent. Small pumps and power supplies have been developed for artificial hearts. These can be further miniaturized to provide the much lower flow rate required for an artificial kidney. During the night, while the patient is asleep, the batteries can be recharged while the pumps are powered from the house supply.

The only disposables are the sorbent cartridge and infusate. These should be no more expensive than the present sorbent cartridge and infusate, since they are one-tenth the size. Assuming the present cost of $25, the cost would be $75/day, or less than $30 000/year.

Kraus *et al.* [8] used a fluid system similar to the one proposed, except that the peritoneal dialysate was regenerated by ultrafiltration, and the fluid ultrafiltered was replaced by fresh fluid. Based on their report of the clinical results, the urea clearance of the proposed wearable artificial kidney should be 27 mL/min and the creatinine clearance 25 mL/min, resulting in a weekly Kt/V of 6.5 and creatinine clearance of 250 L for a 70 kg patient. This greatly exceeds the present goal for continuous PD of 2.0 and 60 L, respectively.

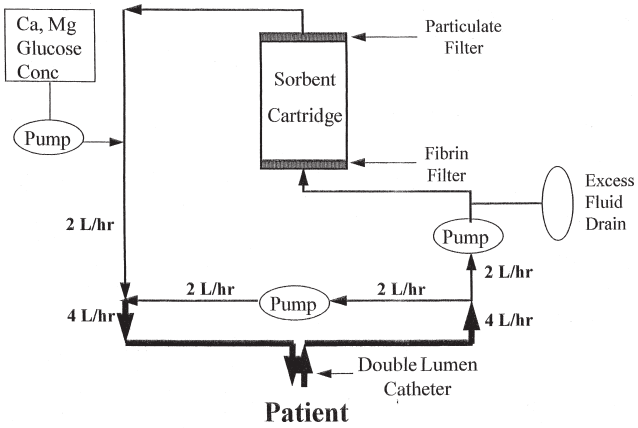

FIGURE 1 Wearable artificial kidney.

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