

# COST-EFFECTIVE DIALYSIS FOR THE DEVELOPING WORLD

Martin C. Gregory, BM, BCh, DPhil

**Introduction:** Dialysis is an effective treatment for end-stage renal disease, but it is available to only approximately half of those who need it in the world.

**Methods:** Two prototype passive-flow dialysate delivery systems were constructed.

**Results:** Each dialysate delivery system provided a flow of dialysate in the range of 200–300 mL/minute. In one example, flow regulation was good, but ultrafiltration could not be monitored. The second prototype could monitor and regulate ultrafiltration but required repeated manual adjustment to maintain nearly constant dialysate flow. Approaches to the remaining obstacles to a fully passive dialysis system are outlined, but these will require further work to prove feasibility.

**Conclusion:** In principle, costs of providing hemodialysis could be reduced and equipment created to function without electricity by exploiting passive-flow techniques. (*Ethn Dis.* 2009;19[Suppl 1]:S1-65–S1-67)

**Key Words:** Hemodialysis, Economical, Passive, Developing Countries

## INTRODUCTION

There is a massive unmet need for dialysis for acute and chronic renal failure in developing nations. Not only is the number of patients immense, but the resources available are severely limited. There are major difficulties in purchasing and maintaining conventional hemodialysis equipment. Peritoneal dialysis is generally of limited help because of difficulty providing sterile dialysate and problems with infection.

## TENTATIVE APPROACH— PASSIVE FLOW DIALYSIS

Hemodialysis can be carried out without the need for a conventional mixer-monitor (“dialysis machine”).<sup>1</sup> This was standard in the days of atrioventricular (AV) shunts and Skeggs-Leonard and Kiil dialyzers.<sup>2</sup> With suitable choices of vascular access, dialysate delivery systems, and dialyzers, simple, inexpensive hemodialysis should be possible. Examples of two prototype dialysis delivery systems are shown in Figure 1. Several potential difficulties, however, must be addressed.

### Obtaining Adequate Blood Flow

For acute renal failure, AV shunts offer relatively low resistance to flow and can provide adequate blood flow (over 200 mL/minute) through a number of dialyzers of relatively low blood flow resistance. For maintenance dialysis in end-stage renal failure, providing adequate blood flow to the dialyzer is more challenging but should be possible from an arteriovenous fistula by compressing the fistula between the arterial and venous needles. At a blood flow of 200 mL/minute, the pressure drop across 15-gauge arterial and venous needles is each  $\approx 30$  mm Hg. The pressure drop across the blood compartment of a Fresenius F8

dialyzer is also  $\approx 30$  mm Hg. Thus a mean arterial pressure of 90 mm Hg could drive blood through this dialyzer at 200 mL/minute. For patients with lower mean arterial pressure than this, wider needles or a redesigned dialyzer configuration would be necessary.

Is it safe to compress a fistula to or close to the point of occlusion for the duration of a dialysis session? Evidence on this point is limited, but we have compressed fistulae that were no longer needed in 3 patients in a deliberate attempt to occlude them. In no case did the fistula thrombose. It appears that in the absence of prolonged hypotension, infection, or fistula stenosis a mature fistula is tolerant of occlusion for several hours. Obviously more information is needed to define safe limits for fistula compression.

### Obtaining Adequate Dialysate Flow

Using 4.5-mm internal diameter polyvinyl chloride tubing connected via Hansen connectors to a Fresenius F8 dialyzer, a pressure head of 60 cm created a flow of  $\approx 200$  mL/minute with each of the 2 delivery systems. This is a feasible pressure head for a practicable apparatus, and a higher dialysate flow can be achieved with slightly wider caliber tubing, if desired.

### Regulating Dialysate Flow

The dialysate flow is determined by the pressure difference between the dialysate source and the sink and by the resistance of the dialysate tubing. The tubing diameter can be chosen to provide the requisite flow resistance to suit the pressure head employed. In the first prototype, the pressure head is maintained constant by a valve that maintains the dialysate level constant in the upper container. In the second prototype, when the dialysate level falls in the source

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From the Division of Nephrology, Department of Medicine, University of Utah Health Sciences Center, Salt Lake City, Utah (MCG).

Address correspondence and reprint requests to: Martin C. Gregory, BM, BCh, DPhil; Division of Nephrology, University of Utah Health Sciences Center; 30 N 1900 E, #4R312; Salt Lake City, UT 84132-2412; martin.gregory@hsc.utah.edu



Fig 1. Prototype passive flow dialysate delivery systems. The system on the left was developed by senior students in the Department of Mechanical Engineering, University of Utah (courtesy J.J. Magda, PhD). The system on the right incorporates a mechanism for weighing the combined fresh and spent dialysate and thus monitoring ultrafiltration. In each case, dialysate flow is provided by gravity

container, the flow rate diminishes slightly: this can be compensated by periodically lifting the container a few centimeters. An air break above the level of the spent dialysate in the sink container ensures that changes of level in the sink do not affect the flow rate.

### Proportioning Dialysate

The simplest way to prepare dialysate is by manual mixing. Either acetate-based or bicarbonate-based dialysate can be prepared by mixing concentrates (or dry reagents) and water in the correct proportions, and either will be stable for the time required for a typical dialysis. Adequate stirring is critical. A Myron-L or similar conductivity meter can be used to check the composition of the final dialysate.

### Measuring Ultrafiltration

In the second prototype shown in Figure 1, the dialysate source and sink are suspended together from a 50-kg capacity fish scale that reads in increments of 0.1 kg. Increases in the combined mass of the fresh and spent dialysate equal the mass of fluid removed from the patient.

### Controlling Ultrafiltration

Ultrafiltration rate (UFR) is directly proportional to the ultrafiltration coefficient of the dialyzer ( $K_f$ ) and the net filtration pressure across the membrane.  $UFR = K_f (P_b - P_d - P_{pp})$ , where  $P_b$  is the pressure in the blood compartment,  $P_d$  is the pressure in the dialysate compartment, and  $P_{pp}$  is the oncotic

pressure of plasma proteins. Modeling these variables shows that UFR could be varied between 0 and 700 mL/hour by adjusting the mean height of the source plus sink between 20 cm above and 50 cm below the patient. Ultrafiltration rate cannot be calculated precisely, and the mean height of the dialysate will require iterative adjustment during dialysis in response to measured ultrafiltration rate and clinical estimates of volemia.

### Warming Dialysate

Warming dialysate will be a trivial problem in hot climates, but may be one of the greatest difficulties in temperate environments. In preliminary experiments, a simple heat exchanger consisting of 1 m of 1 cm internal diameter,

1.5 mm wall thickness stainless steel in a 40-L bucket of water at 40°C kept dialysate temperature close to 37°C at a source temperature of 22°C and a dialysate flow rate of 200 mL/min.

### Adequacy of Dialysis

Dialysis for 3 hours 5–7 days per week at a blood flow of 200 mL/minute and a dialysate flow of 200 or 300 mL/minute should provide a quantity of dialysis similar to that in many daily or nocturnal dialysis programs. The ability to collect all of the dialysate will enable direct quantitation of dialysate-side kinetics and comparison with blood side kinetics.

### Managing Anemia

To avoid the expense of erythropoietin, blood loss will be kept as low

as possible. Short blood lines lacking drip chambers will minimize blood loss with each treatment, and the lack of a blood pump will minimize mechanical trauma to erythrocytes. With slow blood and dialysate flow rates, there will be near equilibrium between blood and dialysate for small molecules by the dialysate effluent, and periodic chemistries could mostly be monitored with spent dialysate analysis rather than blood sampling. Iron could be provided orally or via the dialysate more cheaply and safely than by intravenous infusion.

### CONCLUSION

Although many details remain to be tested rigorously, passive flow dialysis

appears to offer a feasible means of greatly reducing the cost of providing dialysis to patients with renal failure in the developing world. By eliminating the need for a dialysis machine, the availability and reliability of dialysis could be greatly increased.

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