CONSIDERATIONS OF ULTRAFILTRATION CONTROL DURING HAEMODIALYSIS*

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Modifying the pressure gradient between the blood compartment and the dialysate compartment, ultrafiltration is commonly employed to control the transfer of fluid across the membrane. With recirculating dialysis, regulation of ultrafiltration was simple, as the volume of fluid in the dialysate reservoir could be readily assessed. With 'single pass' procedure, ultrafiltration is largely a matter of empiric guesswork, and is usually measured retrospectively by noting the amount of weight lost during the procedure.

It is commonly believed that the degree of ultrafiltration desired can be equated with a prescribed 'negative pressure', i.e., suction applied to the dialysate compartment. We have re-evaluated actual weight loss that occurred from the beginning to end of 713 dialyses in 9 patients. The correlation with applied negative pressure was poor, even when corrections were made for infusions. We reasoned that weight loss measured after dialysis was too crude an estimate of ultrafiltration, as weight changes due to ingestion, excretion, perspiration and catabolism were included. We, therefore, sought to correlate rate of weight loss measured over brief intervals with actual pressure gradients across the dialysers.

TECHNIQUE

In order to study this relationship, an apparatus was assembled utilizing a Potter Bed Balance**, Model 26B, coupled through a low pass filter to a Heath Recorder***, Model EUW-20A, run at 2''/hr, using a ballpoint pen. The pressure in the dialysate compartment was measured by use of a Compur-Tran Corporation potentiometer type transducer****, Model No. 2134-R. Since the transducer operated only in the direction of positive pressure, it was modified to operate with suction or negative pressure by preloading it at 200 mm Hg, using a mercury column.

In order that both pressure and weight could be placed on the same record, a time-sharing multiplexer was constructed which, at two-minute intervals, shifted from the bed scale recording to the pressure recording for a 10-second period, thereby producing a series of short dots and long dashes on the paper, representing the dialysate compartment pressure and the weight. Figure 1 is the electrical circuitry employed. The blood compartment pressure was measured either directly by aneroid manometers in the arterial and venous lines, or from a nomogram developed from this experience which related the mean blood compartment pressure in the kidney to the systolic-diastolic pressures as measured by a sphygmomanometer

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* This study was supported in part by Contract Number PH 43-66-1158, from the National Institute of Arthritis and Metabolic Diseases, National Institutes of Health.

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* $R_3$ - External potentiometric pressure transducer

Fig. 1. Multiplexer circuit.

to within approximately 5 mm Hg (I S.D.). With this apparatus, 39 dialyses on 16 patients were studied; 444 data sets were obtained.

RESULTS

Figure 2 is a typical tracing obtained with such equipment. Since objects were constantly being placed on and removed from the bed during the dialysis procedure, the absolute weight difference was not reliable for more than brief periods. However, the slope of the weight change line proved to be a consistent method of measuring rate of weight change and, hence, fluid loss. Figure 3a illustrates the variation in rate of weight loss for one patient during one day in which the transmembrane pressure gradient was maintained constant at 54 to 57 mm Hg. As can be seen, from minute-to-minute or from hour-to-hour, there is considerable variation in rate of ultrafiltration without any apparent changes in the pressure gradient. These values are the average values for each hour; the 15-minute variations were much greater. Figure 3b illustrates the change from day-to-day for one patient. On each day the pressure gradient was essentially the same (120 ± 10 mm Hg). Figure 4 is a plot relating the rate of weight loss to the pressure gradient for all patients in the series. It can be observed that for any narrow range of pressure gradients the observed weight loss rate extends over practically all the full width of clinical weight loss sought.

DISCUSSION

It is apparent that wide variations exist in the association between weight loss achieved and pressure gradient utilized in haemodialysis. This association is a probable reflection of the magnitude of the osmotic and hydrostatic forces involved. The osmotic pressure of the blood is in the order of 5,000 mm Hg. In theory, this is balanced by the osmotic pressure of the dialysate which is substantially due to the Na$^+$ and Cl$^-$ ions present. Thus, an imbalance of as little as 1.5% of the forces involved would be equivalent to almost 75 mm Hg pressure, which is as great as the usual adjustments made to effect maximum ultrafiltration. Ingestion of about 600 ml distilled water, or 5 g NaCl without water, will change the concentration
**Fig. 2.** Example of weight loss and negative pressure recording.

**Fig. 3a.** Weight loss rate variations at constant pressure gradients. Hourly during one dialysis.
Fig. 3b. Weight loss rate variations at constant pressure gradients. Daily with repeated dialyses.

Fig. 4. Weight loss rate versus pressure gradient.
of the total body water by this 1.5%. The problem is further compounded by the fact that glucose is added to dialysate in higher concentration than it is in blood. Since glucose moves across the dialyser membrane in the opposite direction to the gross movement of fluid, there is some attenuation of the ultrafiltration mediated by the osmotic gradient. Physiologic changes in sodium concentration may similarly affect water transfer. Because water movement is strongly affected by the osmotic gradients, prediction of water movement for any particular external gradient of applied transmembrane hydrostatic pressure is unreliable. A logical approach to the problem of regulating ultrafiltration would be to utilize the basic concepts developed in modern control theory and operate in a ‘closed loop mode’, i.e., adjust the pressure gradient to achieve the desired results by continuous measurement of water transfer and, using this information in turn, to readjust the pressure gradient as needed. This measurement of water transfer can be achieved by either volumetric or gravimetric measurement of the dialysate inflow and outflow, or by continuous weighing of the patient. Although devices for regulation of negative pressure are readily designed, at the present state of the technology it is not considered advisable to utilize an unsupervised fully automatic control system.

Summary

The rate of ultrafiltration during ‘single pass’ haemodialysis correlates poorly with the transmembrane pressure gradient. This is probably due to minor fluctuations in osmotic pressure in the blood compartment. The use of a continuous weighing device to serve as the input signal to regulate ‘negative pressure’ is discussed.