THE INFLUENCE OF DIALYSATE VOLUME AND FLOW RATE ON PERITONEAL CLEARANCE

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The main disadvantage of peritoneal dialysis as compared to haemodialysis has been its relatively low efficiency. Careful clearance studies (Boen, 1961, 1964) indicated that flow rates of about 3 litres per hour were optimal and yielded average urea clearances of 25 ml/min. However, flow rates of 3 litres per hour were in many instances prohibitive because of the high costs of commercially available dialysis fluid. The development of new dialysate manufacturing techniques in our laboratory made large volume dialysis economically feasible and stimulated us to reevaluate the effect of volume flow and rate on peritoneal clearances.

Methods

During the past 18 months we studied two patients on chronic intermittent dialysis and more recently also a number of patients undergoing peritoneal dialysis for acute renal failure. The chronic patients were metabolically stable, they were not catabolic and took a well-balanced but moderately protein-restricted diet (approximately 1 g/kg body weight). The acute patients were critically ill and quite catabolic.

As a rule, each dialysis was divided into 2 clearance periods, one at low flow rates and one at the maximal flow rate that could be obtained. Occasionally one dialysis was subdivided into 3 or 4 clearance periods. The flow rate of the first clearance period was alternately fast or slow. Clearance periods varied in duration but extended at least over 3 hours. The minimal outflow volume was 20 litres of dialysate. Clearances for urea, creatinine and phosphate were calculated using van Slyke's formula: \( C = \frac{UV}{P} \) in which \( U \) represents the concentration in the dialysate outflow, \( V \) the volume of the dialysate outflow and \( P \) the plasma concentration.

After the insertion of the peritoneal catheter and immediately before the start of the dialysis, a venous blood sample was drawn and repeated blood samples were obtained at the end of each clearance period and at the end of the dialysis. Blood samples were immediately spun down and refrigerated until analysed on the same or the following day by the use of a Technicon Autoanalyzer.

The intermittent flow technique was used throughout and the dialysate temperature was kept constant at 38°C by means of a thermistor monitored hotplate. In order to obtain maximal flow rates the diffusion time was shortened from 20 minutes to 30 seconds, the shortest time our automatic cycling machines will allow. The total cycle length, comprising inflow, outflow, and diffusion time became thus a function of the ease of dialysate inflow and outflow which is dependent on the position of the peritoneal catheter. During each inflow period 2 litres of dialysate were allowed to flow into the abdomen and the outflow was adjusted to permit complete recovery of the inflow volume plus any fluid removed in excess. Once the desired cycle length was established, it was kept constant during the entire clearance period by the use of the automatic cycling machine.

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Results

A total of 590 clearances were obtained from the two patients on chronic intermittent dialysis: 199 urea clearances, 200 creatinine clearances, and 191 phosphate clearances. Satisfactory clearance studies in acute patients could be obtained in only 18 instances. Although these followed the same trend, their small number and the great variation in the catabolic state of the patients caused us to exclude their data from this presentation.

![Graph showing peritoneal clearances vs. dialysate flow rate](image)

*Fig. 1.* Peritoneal clearances for urea in relationship to flow rate. Straight lines connect urea clearances at lower and higher flow rates, each obtained in the course of one dialysis.

In Figure 1 some typical results obtained during several dialyses at varying flow rates are shown. The urea clearance values obtained at low and high flow rates during each dialysis are connected by straight lines. The data are from a patient (M.O.) who is peritoneally dialysed since eighteen months. The patient has been well all this time, she never had abdominal surgery or peritonitis. Figure 2 depicts the peritoneal urea clearances of this patient in relationship to flow rates. The regression line and 95% confidence limits are drawn for the observed flow rates which range from two litres per hour up to 11.8 litres per hour. It can be seen that urea clearances are doubled (from an average of 20 ml/min. to 41 ml/min.) by increasing dialysate flow rates from two to ten litres per hour. The increase is statistically significant below the one per cent level. The scatter is wide, particularly in the lower range, probably due to factors that cannot be regulated at will such as mixing and pocketing of dialysate within the peritoneal cavity.

![Graph showing peritoneal urea clearances vs. dialysate flow rate](image)

*Fig. 2.* Peritoneal urea clearances in relation to flow rate of patient, M.O., with regression line and 95% confidence limits.
Figure 3 shows the regression lines for urea, creatinine, and phosphate of the same patient. The number of clearances performed for each substance is entered in brackets.

![Graph showing regression lines for urea, creatinine, and phosphate](image)

*Fig. 3. Peritoneal clearances for urea, creatinine and phosphate in relation to flow rate of patient, M.O. The number of clearance studies performed is added in brackets.*

The other patient studied (J. D.) showed a similar increase in clearances when dialysis flow rates were increased. The slopes of the regression lines for urea, creatinine and phosphate, however, are less steep and we were not able to obtain flow rates in excess of 8 litres per hour. We attribute these differences at least in part to the fact that the patient, on regular dialysis for 2½ years, had peritonitis in the early course of the treatment when she carried an implanted peritoneal access tube. She also had repeated abdominal surgery and probably has intra-abdominal adhesions. Her parietal peritoneum is noticeably thickened. As in the other patient the regression line for creatinine crosses that of urea at higher flow rates.

**Discussion**

A variety of factors influence peritoneal clearances, some of which can be controlled by the physician, others are beyond our control. Obviously the clearance is dependent on the surface area that is available and the degree of its vascularity. The peritoneal surface area has been measured as approximately 2.2 square metres for an adult of average size. In the clinical application of peritoneal dialysis, however, we cannot assume that the entire surface area does actually participate in the exchange. Depending on the position of the catheter and the patient only part of the available surface area may be utilized or fluid may be trapped in pockets that do not well participate in fluid exchange. We have little control over these factors which probably explain the rather wide scatter of all peritoneal clearance data.

The factors that we can control are the temperature of the dialysis fluid which should be at body temperature since cold fluid causes vasoconstriction and impedes exchange; we can also regulate the flow rate of the bathing fluid. This is dependent on the position of the catheter which should be deep in the sacral fossa and yet allow free inflow and outflow. At times the physician will have to be content with less ideal positioning of the catheter and this will reflect itself in the clearance values obtained.

Earlier studies in acute patients (Boen, 1964) indicated that peritoneal urea clearances decreased at flow rates above 3½ litres. As can be seen from Figure 4 which is taken from Boen's book on peritoneal dialysis, there were only few clearances performed at flow rates higher than 3 litres. The means of these earlier values fall within the 95% confidence limits of our recent studies which are superimposed on his original data. The suggested decline of clearances at higher flow rates is accounted for then by insufficient data at higher flow rates. Our results indicate that the relation between flow rate and clearance is linear or nearly linear in the range we were able to study. The slope of the regression lines for creatinine is steeper than that of urea in both patients. This is due to an analytical error caused by high dextrose concentrations in
the dialysate outflow. By adding equivalent amounts of dextrose to our analytical standards, this mistake has since been eliminated and the correct regression lines for creatinine were found to be lower and less steep.

![Diagram](image)

Fig. 4. The thick lines represent earlier data obtained by Boen during peritoneal dialysis for acute renal failure (1964). The superimposed thin lines represent the regression line and 95% confidence limits of our more recent studies. The earlier results of Boen erroneously indicated a decrease in peritoneal urea clearances due to insufficient data.

Whereas the lower end of the dialysance curves has been sufficiently studied, the upper limits of the rapid flow dialysis system remain to be established. It is obvious that somewhere at higher flow rates the curves must level off with little further increase in clearances with increasing flow rates. Earlier this year McDonald (1965) indicated, without presenting any data, that peritoneal clearances can be increased by employing higher dialysate flow rates. Using a recirculating continuous flow technique, Shinabager et al. (1965) reported two- to threefold increases in peritoneal clearances with flow rates of 18 litres per hour. Combining their data with ours it becomes clear that at flow rates of about 10 to 12 litres the curves must level off, and little is to be gained by further increasing flow rates. With a slightly modified catheter, which we are testing now, flow rates in this range should be obtainable during most dialyses even with the intermittent flow technique.

In a few instances we have studied the effect on clearances if volumes smaller than 2 litres for each inflow period were employed. The results indicate that the dialysate volume per cycle may be lowered to 1.5 litres, and possibly further, without significant loss of efficiency, using the rapid flow system. The optimal flow rate to volume ratio remains to be established.

No significant increase in total protein losses were observed with the faster dialysis. We were, however, surprising that at higher flow rates excess fluid removal was reduced and higher dextrose concentrations had to be used in order to remove excess fluid.

**Summary**

Evidence is presented that peritoneal clearances can be increased two- to threefold with increasing dialysate flow rate from 2 to 12 litres per hour. The relation between flow rate and clearance seems to follow a straight line within the range that was studied. It appears that the dialysance will level off at flow rates above 12 litres per hour and that little is to be gained by increasing flow rates further. Rapid flow high volume peritoneal dialysis increases the efficiency of peritoneal dialysis, thus shortening the time required for adequate dialysis. The rapid flow dialysis is equally well tolerated by the patient as the conventional peritoneal
dialysis at low flow rates, and the development of new dialysate manufacturing techniques makes dialysis at flow rates of this magnitude economically feasible.

REFERENCES


