Chapter 3

Physiology and Techniques of Modalities for Chronic Renal Dialysis

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The purpose of this chapter is to acquaint the nonmedical reader with the methods of dialysis that have been developed to substitute for kidneys whose function has deteriorated below a level that can support life. [1] Most attention is focused on hemodialysis (HD), the historical standard of medical treatment for renal failure, and on continuous ambulatory peritoneal dialysis (CAPD). Only brief mention is made of the less widely used approaches (e.g., continuous cycling peritoneal dialysis [CCPD] and intermittent peritoneal dialysis [IPD]).

[1] See Appendix B.—*Glossary of Acronyms and Terms* for definitions of selected medical terms.

HEMODIALYSIS

Principles and Physiology

HD depends on the concept of circulating a patient's blood outside the body through a thin-walled synthetic tube or group of tubes (dialyzer), which are bathed in aqueous solution (dialysate). The semipermeable properties of the dialyzing membrane permit the exchange of selected dissolved substances (solutes) between the dialysate and the blood. Dialysis, crudely, may be likened to the exchange that takes place through the screen of a porch. The screen permits free passage of air to and from, since air molecules are much smaller than the screen's mesh. Large insects are totally unable to pass through the screen, but smaller insects or other airborne particles may be able to penetrate with some difficulty or delay. With current HD technology, blood circulates through thousands of hollow capillary fibers which are bathed in a continuously flowing dialysate that is discarded after a single passage past the fibers.

During HD, small molecules (e.g., urea and creatinine) diffuse rapidly from the blood through the membrane and into the dialysate. HD, therefore, is ideally suited to adjust the concentration of these small molecules in the blood and in other extracellular fluid compartments of the body that are in free communication with the blood. Equilibrium occurs more slowly, however, with body compartments that are more remote from the circulating blood, including intracellular fluid and cerebrospinal fluid. Middle molecules diffuse through the dialyzing membrane more slowly, and large molecules such as proteins (molecular weight 50,000 and greater) are effectively blocked.

In clinical practice, the composition of the dialysate is adjusted carefully to minimize excessive disturbances in the water and salt balance of the body and, hence, to reduce the small but finite risk of hypertensive crises, cardiac arrhythmias or circulatory collapse. The volume of dialysate, the surface area of the dialyzer, the rate of flow of blood through the dialysis tubing, and the duration and frequency of dialysis sessions are tailored to the needs of the individual patient.

Technique

The application of HD requires access to the patient's circulation. Originally, this was accomplished by inserting a cannula into a superficial artery, which was then connected by external tubing to a cannula in an adjacent vein. These connections formed an arteriovenous connection, or fistula. In recent years, the cannula and external tubing have been replaced by a direct anatomosis between the artery and vein beneath the skin which is accessed by large bore needles at the time of dialysis. This latter technique has greatly reduced the risk of infection. Most commonly, the arteriovenous fistula is placed in the forearm, but other sites are possible if occlusion of the fistula or local infection requires its relocation.

HD requires two or three dialysis sessions per week, each lasting 3 to 5 hours. During dialysis the arteriovenous fistula is connected to the dialyzer, and dialysis solution is circulated past the dialyzer at an average rate of about 500 ml/min. The patient usually is given an anticoagulant, heparin, to prevent the blood from clotting as it circulates through the dialyzer.

HD may be administered in a hospital, in an independent dialysis center, or at home. The first two options are collectively referred center *HD* or *facility HD.* Alternatively, the patient may purchase or lease the dialysis equipment and receive dialysis treatments at home with the aid of family, friends, or salaried assistants. This is known as *home HD.*

CONTINUOUS AMBULATORY PERITONEAL DIALYSIS

Principles and Physiology

Like HD, CAPD is based on the principles of diffusion of fluids and solutes across a semipermeable membrane. In the case of CAPD, however, the dialyzing membrane is the membrane lining the abdominal cavity (peritoneum). Instead of the patient's blood being circulated outside the body, the normal capillary circulation that supplies the peritoneum is used. During each exchange, up to 2 liters of dialysate is introduced into the peritoneal cavity through a catheter that penetrates the abdominal wall and is left for 4 to 8 hours before being removed through the same catheter by gravity drainage.

The composition of the dialysate is adjusted so that the transfer of fluid and solutes favors normalization of the patient's fluid and electrolyte balance. The transfer of water across the peritoneum is controlled by the concentration of glucose in the dialysate. Higher concentrations of glucose favor the transfer of water into the peritoneal cavity. Thus, if a patient is overhydrated, excess water can be removed. This feature of CAPD can be particularly advantageous in the patient with hypertension or edema. In some diabetics, insulin may be introduced into the dialysate, thereby obviating the need for daily insulin injections.

The small volume of dialysate used in CAPD results in a rapid decrease in the concentration gradient during an exchange. Since a high gradient favors the diffusion of low molecular weight solutes from the patient to the dialysate, transfer will be rapid initially but will then decrease to the point that relatively little net transfer takes place towards the end of a period. CAPD, therefore, is less efficient than HD in eliminating low molecular weight solutes. The "middle" molecules mentioned previously are removed more effectively, however, because the effective pore size of the peritoneum is larger than that of the HD dialyzing membrane.

In contrast to the intermittent nature of HD, the multiple daily exchanges of CAPD result in essentially continuous dialysis. There are several consequences. Fluctuations in concentrations of solutes are relatively small during CAPD, and rapid changes of fluid volume are avoided. Furthermore, the equilibrium between body fluid compartments (blood, extracellular fluid, intracellular fluid, and cerebrospinal fluid) is disturbed less than with HD. The clinical significance of this latter phenomenon is not completely known but is at least a theoretical advantage of CAPD.

Although changes in the filtration characteristics of the peritoneal membrane might be expected to occur during the long-term use of CAPD, observations over intervals of months to several years have not consistently demonstrated measurable effects.

Technique

Analogous to the need for vascular access in HD, CAPD requires that a catheter be placed in the peritoneal cavity to permit exchanges of dialysate. The original technique to insert the catheter (a Tenckhoff® catheter with multiple terminal perforations or some modification) required a hospital admission and a "mini''-laparotomy. A more recent technique permits the catheter to be placed percutaneously through a stylus, thus avoiding the need for a laparotomy and hospitalization.

The catheter is placed in a dependent position in the peritoneal cavity in a manner that minimizes the likelihood of catheter obstruction and the risk of erosion into other abdominal organs. It is then led out obliquely through a subcutaneous track to decrease the risk of subsequent infection. There are several types of devices that place flanges and spongy materials around the catheter to reduce the likelihood of fluid leaks from the peritoneal cavity and to impede the migration of bacteria.

When CAPD is first begun in a patient, an automated cycling machine is often used to facilitate exchanges. Thereafter, exchanges are performed by gravity feed. The volume of fluid exchanged depends on the size and tolerance of the patient and ranges from **500 cc** in children to *3,000 cc,* with an average for adults being between 1,500 and 2,000 cc. Four or five exchanges are performed daily, including one exchange in which the dialysate remains in the abdomen overnight. The exchange procedure takes 30 to 45 minutes and requires a moderate amount of physical dexterity. Meticulous, sterile techniques must be followed while connecting the dialysate bag to the peritoneal catheter (a process called "spiking") to prevent infection of the peritoneal cavity (peritonitis). The long-term compliance required with these exacting procedures may be extremely difficult for some patients.

Recent technical advances in CAPD have centered on reducing the risk of peritonitis. Several approaches have been proposed, including:

- *Sterile Connection Device (SCD)® (Dupont Co.):* This device eliminates the need to manually "spike" the dialysate bags to connect them to the peritoneal catheter tubing by performing a sterile "heat-weld" between the tubes of the dialysate bag and that of the catheter.
- *Peridex CAPD Filter Set® (Millipore Co.):* A filter is placed in the line conveying dialysate to the peritoneum to remove bacteria or fungi that may have contaminated the system during "spiking." Each filter is designed for 2 weeks of use.
- *CAPD UV Germicidal System® (Travenol Laboratories, Inc.):* Ultraviolet light is used to sterilize the connection between the dialysate bag and the catheter or its extension. This system improves sterile technique but does not eliminate the need for the manual "spiking" procedure.

Although each of these approaches has promise, none has yet been shown to actually reduce peritonitis rates in properly controlled studies.

Two other relatively infrequently used techniques for peritoneal dialysis deserve mention:

- *Intermittent Peritoneal Dialysis (IPD):* This technique is similar in principle to CAPD but involves intermittent dialysis sessions of up to 10 hours each 3 or 4 days a week during which dialysate exchanges are cycled at rates of about 2 liters per hour. Schedules are highly individualized to the needs of the individual patient.
- *Continuous Cycling Peritoneal Dialysis (CCPD):* CCPD is very similar to CAPD but employs a machine that permits continuous dialysate exchanges to be performed automatically during sleep. Dialysate volumes of 10 liters or more are cycled, but not more than 2 liters are in the abdominal cavity at any one time. This technique obviates the inconvenience of multiple daily exchanges and may reduce the risk of peritonitis.

COMPARATIVE EFFICIENCY OF DIALYSIS BY HEMODIALYSIS AND CONTINUOUS AMBULATORY PERITONEAL DIALYSIS

Table 3-1 provides comparisons between the efficiency of dialysis by HD, CAPD, and IPD as measured by urea clearance (ml/min) and weekly urea clearance (L/week). The results are from a single study **(29)** and are based on the dialysis requirements of a **70** kg individual with a urea gen-

Table 3-1.-Strategies for Solute Removal With Hemo- or Peritoneal Dialysis to Maintain Average BUN = 80 mg/dl[a]

Method of dialysis	Urea clearance during treatment (ml/min)	Treatment (hr/wk)	Urea clearance (L/wk)
Hemodialysis	150	15	135
Intermittent peritoneal dialysis	22	64	85
Continuous cycling or continuous ambulatory peritoneal dialysis	35	40	85
	7	168	70

[a]BUN (Blood Urea Nitrogen). The source from which this table was taken does not make the distinction between a time averaged BUN and predialysis BUN for patients receiving hemodialysis. Lowrie indicates that a predialysis BUN of 60 mg/dl is equivalent to an average BUN of 50-60 mg/dl in patients being treated with hemodialysis.

SOURCE: A. S. Levy and J. T. Barrington, "Continuous Peritoneal Dialysis for Chronic Renal Failure," *Medicine* 61:330-339, *1962.*

eration rate of 5.7 mg/min and no residual renal function. Other studies provide similar, though not identical, findings.

HD is the more efficient method of dialysis. Urea clearance per unit of time by HD is twice that of two normal kidneys and more than *20* times that with CAPD. Because dialysis treatment time with CAPD *(168* hours per week) is much longer than that with HD (9 to 15 hours per week), the weekly urea clearance by CAPD is slightly *over* half that provided by HD (70 vs. 135 L/wk).

Controversy is brisk over whether the amount of dialysis provided by CAPD is clinically adequate, since it is less than that provided by HD as measured by urea clearance (30). This controversy, in large part, is related to uncertainty over the nature of the toxic substances responsible for the signs and symptoms of the uremic state. Nephrologists who believe that urea clearance serves as an appropriate marker for the removal of other toxic substances point to the greater efficiency of HD, while other nephrologists who believe that "middle molecules" are important emphasize the greater ability of CAPD to remove these substances and downplay implications of differences in urea clearances. As of this writing, this controversy is unresolved.