

The Emergence of Peritoneal Dialysis

In the 1970's interest in another form of dialysis -- peritoneal dialysis -- began to grow. Actually, the concept had been discussed and tried in creative fashion by several researchers beginning in the 1700's. But it was not until the 1970's that clinical investigation into the use of peritoneal dialysis intensified. The renewed interest came in response to the need for a way to treat patients who either were not good candidates for hemodialysis or who were seeking a less rigid form of care.

In contrast to hemodialysis, which cleanses the blood outside the body, peritoneal dialysis works "inside the body," using the body's own peritoneal membrane as the semipermeable barrier through which the blood can be filtered.

Dialysis solution is introduced directly into the patient's peritoneal cavity through a catheter; the cavity is used as a reservoir for the dialysis solution. Toxins in the blood filter through the peritoneal membrane into the cleansing solution, which is then withdrawn from the body through the same catheter and discarded.

Peritoneal Dialysis was originally used only as an intermittent procedure, but the newer forms of peritoneal dialysis allow patients to self-administer the procedure four or five times daily on a continuing basis at home or "on the road." Patients sleep or go about their daily activities while dialysis occurs internally.

The Early Peritoneal Dialysis Investigators

The initial concept of peritoneal dialysis may have evolved from a novel treatment developed in the early 1740's by Christopher Warrick, in England. Warrick presented his findings at a meeting of the Royal Society, and in 1743 Reverend Stephen Hales wrote about modifications to the procedure. ⁵⁰

Warrick was treating a 50-year-old woman who was suffering from severe ascites -- a collection of fluid in the peritoneum. He decided to instill Bristol water and claret wine into the patient's peritoneum through a leather pipe -- the assumption being that the wine would have an antibacterial effect. The patient reacted so violently that the therapy was discontinued after three treatments. It is interesting to note, however, that she did recover from the ascites in a period of weeks, and, according to Warrick, in a short time she was able to walk seven miles in a day without difficulty.

The early investigators were primarily interested in the capacity of the peritoneal membrane to remove toxins, such as urea; they were not yet focusing on its potential for removing fluid. Over a period of years, a series of findings concerning peritoneal function brought investigators closer to the realization of how the peritoneal cavity and membrane could be used to cleanse the body of these toxins.


G. Wegner, in Germany, determined the absorption rate of various solutions from the peritoneum as early as 1877. ⁵¹

E. H. Starling and **A. H. Tubby** first described the fluid removal characteristics of the peritoneum in 1894. ⁵² And in 1895, W. N. Orlow pointed out that fluid absorption occurs from the peritoneal cavity. ⁵³

In 1918, **Desider Engel**, working first in Prague and then in China, demonstrated that protein can pass through the peritoneal membrane. ⁵⁴ This significant finding was applied by later investigators in their efforts to show that peritoneal dialysis may be more efficient in removing large molecules.

In 1919, **M. Rosenberg** noted that the same fluid in the peritoneum contained the same amount of urea that is found in the blood, indicating that urea could, in fact, be removed using peritoneal dialysis. ⁵⁵

And it was in 1923 that **Tracy Putnam** ([Figure 132](#)), at Johns Hopkins University, suggested that the peritoneum might be used to correct psychological problems. ⁵⁶

 Figure 132:
Tracy Putnam,
M.D.


Early Clinical Applications of Peritoneal Dialysis

Georg Ganter – The First Clinical Application of Peritoneal Dialysis.

The first clinical application was performed by **Georg Ganter** ([Figure 133](#)), in Germany in 1923. ⁵⁷ Ganter was looking for a dialysis procedure that did not require the use of hirudin, a substance that was used to prevent blood from clotting, but which was toxic to humans.

Ganter refined a technique, described by Rowntree and others, that used the peritoneum as the dialyzing membrane and did not require the use of an anticoagulant.

He prepared a sterile physiological solution that contained the proper amount of electrolytes with dextrose added for fluid removal. The solution was placed in large bottles that were then boiled to insure that the bacteria had been killed. The solution was instilled into the patient's peritoneum through a simple hollow needle, with rubber tubing serving as the conduit between the bottle and the needle.

 Figure 133:
George Ganter,
M.D.

The first patient treated with this system was a woman who had suffered renal failure following childbirth. In a series of "exchanges," Ganter instilled from 1 to 3 liters of solution into the peritoneum and let it dwell from 30 minutes to three hours each time. He continued to do the exchanges until the blood chemistries became more acceptable, at which time he sent the patient home. The patient subsequently died, and Ganter noted that he had not been aware that he would have to continue the therapy in order to keep the patient alive.

Ganter made a number of important observations on treating patients with peritoneal dialysis that are still valid today. He commented on the importance of adequate access and noted that while it was easy to instill the solution into the peritoneum, it was very difficult to maintain adequate outflow because of the needle access. He was also aware of the problem of infection and stated that this was the most frequent complication he encountered in using the procedure.


Ganter identified the following principles of peritoneal dialysis, which remain important today:

- Adequate access is of primary importance
- Sterile solutions help prevent infection
- Fluid removal is determined by the dextrose concentration
- Dwell time and fluid volume affect solute clearance.

Stephen S. Rosenak – Development of a Catheter


Also, in the early 1920's, **Stephen Rosenak** and **P. Sewon**, working in Europe, developed a metal catheter for continuous lavage of the peritoneum that helped overcome some of the problems with access. ([Figure 134](#))⁵⁸

In time, however, Rosenak became very discouraged with peritoneal dialysis because of the frequent incidence of peritonitis and he, instead, turned his attention to designing dialyzers for hemodialysis.

 Figure 134: First Peritoneal Catheter made from steel wire and other metal components. Developed by Rosenak and Sewon.

Wear, Sisk, and Trinkle – First Continuous Treatment of a Patient with Peritoneal Dialysis

The next significant event in the development of peritoneal dialysis occurred at the Wisconsin General Hospital in 1936. A group headed by J. B. Wear ([Figure 135](#)), I. R. Sisk, and A. J. Tinkle used peritoneal dialysis on a patient who was suffering from urinary obstructive disease. ⁵⁹ They were able to maintain the patient on continuous dialysis until the obstruction was resolved, demonstrating for the first time that a patient could be safely treated with continued peritoneal dialysis.


 Figure 135: J. B. Wear.

P.S.M. Kop -- Use of Gravity to Instill Dialysis Solution

P.S.M. Kop was an associate of Willem Kolff's in Holland during the mid-1940's. It was Kolff's work with hemodialysis that kept alive an intense interest and belief in the value of dialysis treatment among numerous researchers. Kop, however, turned his attention to peritoneal dialysis. ⁶⁰

Kop created an integrated system that used gravity as the means to instill the dialysis solution into the patient's peritoneal cavity. The system used components that could be easily sterilized: porcelain containers to hold the solution, latex rubber tubing to carry the solution down to the patient, and a large glass catheter to instill the solution into the patient's peritoneal cavity ([Figure 136](#)).


Kop's group treated 21 patients and met success with ten of these treatments.

 Figure 136: Kop's gravity-fed peritoneal dialysis delivery system.

Seligman, Fine, and Frank -- Recovery from Renal Failure Using Peritoneal Dialysis

Just as World War I before it, and the Korean War that followed, World War II was the stimulus for research in many areas in medical care. War tends to present difficult treatment challenges in much larger patient populations than in peacetime, and the nature of the situation dictates the need to resolve these medical needs as quickly as possible with minimal concern for cost.


Thus, when researchers at Beth Israel Hospital in Boston, Massachusetts, were directed to find a method to treat renal failure under battlefield conditions, Arnold

 Figure 137: Howard Frank, M.D., Arnold Seligman, M.D. and Jacob Fine, M.D.

Seligman, Jacob Fine, and Howard Frank ([Figure 137](#)) directed their efforts to peritoneal dialysis. ⁶¹

Their system, which was similar to that used by Kop, addressed several technical issues, such as optimal flow rates and modification of the solution to suit patient needs. To prevent bacterial contamination, they used large bottles of solution that were sterilized, and they used two catheters to minimize any potential obstruction during the outflow phase of the procedure ([Figure 138](#)).

In 1945, the Seligman group used their system to treat a patient who was suffering from acute renal failure induced by an overdose of sulfa drugs. The patient's successful recovery is one of the primary milestones in the development of peritoneal dialysis.


 Figure 138: frank-Seligman peritoneal dialysis system.


Arthur Grollman – Forerunner of Contemporary Intermittent Peritoneal Dialysis

Progress with peritoneal dialysis slowed until 1952, when Arthur Grollman ([Figure 139](#)), working at the Southwestern Medical School in Dallas, published a book on the subject. ⁶² In his book, Grollman described the use of a 1-liter container with a cap that connected to a piece of plastic tubing. The tubing was then attached to a polyethylene catheter. The catheter was revolutionary --first, because it was flexible in design and, second, because by making very small holes in the distal end he was able to keep the patient's body tissue from impeding the drainage; the result was better inflow and outflow of the fluid ([Figure 140](#)).

Grollman suggested that the fluid be instilled by gravity and that it should dwell for 30 minutes, at which time it would be drained out into the same container. He suggested that the technique be repeated on an hourly basis until the patient's chemistries returned to normal.

Grollman's book is a classic in that it describes the intermittent method of peritoneal dialysis that we use today.

 Figure 140: Grollman's peritoneal system, using a flexible catheter.

 Figure 139: Arthur Grollman, M.D.

Morton Maxwell -- Simplifying Peritoneal Dialysis

Morton Maxwell ([Figure 141](#)) had been involved with acute hemodialysis at the Wadsworth V. A. Hospital in Los Angeles during the latter part of the 1950's. ⁶³ It was his feeling that hemodialysis was too difficult for most practitioners to use.

Maxwell reviewed the work of Seligman, Fine, and Frank as well as that of Grollman, and decided that he would attempt to put together a peritoneal system to treat acute renal failure.

He was looking for a simple system that would be easy for medical personnel to set up and use. And in order to prevent infection, he designed the system to require as few connections and disconnections as possible.

One of Maxwell's first tasks was to convince a local manufacturer of intravenous solutions to develop a peritoneal solution, to custom design a container for it, and provide a plastic tubing set and a polyethylene catheter.

The technique Maxwell used was quite simple: Instill 2 liters of peritoneal solution into the peritoneum; let it dwell for 30 minutes; then drain the fluid into the original bottles. The procedure was continued until the patient's blood chemistries were normal. Maxwell performed a number of successful peritoneal dialyses using this method ([Figure 142](#)).

Maxwell's techniques and results, published in 1959, were highly regarded for their simplicity and medical significance by the medical community. The procedure became known as the "Maxwell Technique."

A turning point had been reached: dialysis was no longer relegated only to those hospitals that had specialized hemodialysis equipment; now it could be performed in any hospital where the supplies were available and the peritoneal procedure was understood.




 Figure 141: Morton Maxwell, M.D.

 Figure 142: The

Paul Doolan -- Designing a Peritoneal Dialysis Catheter

During the Korean War, a group headed by Paul Doolan ([Figure 143](#)) at the Naval Hospital in San Francisco, also explored the use of peritoneal dialysis as it would be used under battlefield conditions. ⁶⁴ With the help of William Murphy, who had worked with

 Figure 144: Arthur Grollman, M.D.

 Figure 143: Paul Doolan, M.D.


John Merrill's group at the Peter Bent Brigham Hospital in Boston, Doolan's group developed a unique catheter for long-term use. The catheter was made of polyethylene - chosen for its flexible properties - and contained a number of grooved segments that prevented blockage of drain holes and maximized drainage ([Figure 144](#)). Doolan's suggestion that this device could be used long term indicated that researchers were now considering the potential of peritoneal dialysis for chronic use.

Richard Ruben - First Chronic Treatment with Peritoneal Dialysis

The research and development activity in peritoneal dialysis at the Naval Hospital did not go unnoticed. A young physician, Richard Ruben ([Figure 145](#)), who was finishing his tour of duty in the Navy in 1956, was asked to see a woman who had gone into renal shutdown. He decided to treat her with the "Doolan Technique." 65

Ruben implanted the Doolan catheter into the patient's abdomen and began to do peritoneal exchanges for a 24-hour period. The patient's condition improved so dramatically that Ruben was encouraged to continue. As each week came to a close, the patient's condition would deteriorate, and she would require additional dialysis. And each week, after a day of treatment, her condition would improve dramatically. Seeing this pattern, Ruben allowed the woman to spend her weekdays at home and to have her treatment each weekend. This pattern of treatment was continued for three months without the need to remove the catheter; the catheter was replaced once in the 7-month treatment period.

Chronic dialysis, as we know it today, became the focus of renal care in 1960. By gaining continuous access to the blood supply, Scribner and others could provide their hemodialysis patients with chronic care. But the lack of hemodialysis resources and funding for care of dialysis patients led Scribner to propose peritoneal dialysis as an alternative treatment - a way to overcome logistic and financial constraints.

 Figure 145:
Richard Ruben,
M.D.

Advances in Peritoneal Dialysis

Fred S. T. Boen - Automated Peritoneal Dialysis

In 1960, Scribner invited Fred Boen ([Figure 146](#)) to come to Seattle and set up a chronic peritoneal dialysis program that would allow patients to be treated at home. Boen had dialyzed patients using a system similar to the one that was used by Kop in Holland, and he has written a thesis on the kinetics of peritoneal dialysis in 1959, which had attracted considerable attention in the dialysis community. 66


Working with George Shilipetar and others at the University of Washington, Boen developed an automated unit that could be operated unattended during the night ([Figure 147](#)). This system used 40-liter "carboy" containers that were filled and sterilized at the University of Washington; the bottles were then delivered to the patient's home and were returned to the University after use ([Figure 148](#)). Boen's group also developed an automatic solenoid device that would open and close a switch to meter the fluid in and out of the peritoneum.


Boen attempted to use a permanently indwelling peritoneal access tube into which he could insert and remove a long catheter. After each treatment, the catheter was removed and indwelling tube was capped. The problem was that this open system was quite vulnerable to peritonitis, forcing Boen to abandon the technique. He then turned to an intermittent method in which a new catheter was placed into the peritoneum before each procedure and removed on completion of the treatment. Boen adapted his intermittent technique to home use. 67 A physician would go to the patient's house, insert the catheter, begin the exchange, and then leave after the procedure had begun. On completion of the treatment, which would last for about 24 hours, the patient's caregiver would shut down the machine and help the patient remove the catheter. The wound would be covered with a bandage, and the patient would lead a normal life until the next weekend when dialysis would be preformed again.


Although the dialysis procedure itself became quite routine, the logistical support required prevented widespread use of the technique.


Henry Tenckhoff - Simplifying the Delivery System

In 1963, Henry Tenckhoff ([Figure 149](#)) accepted a position at the University of

 Figure 146:
Fred S. T.
Boen, M.D.

 Figure 148:
40-liter

 Figure 147:
Boen's
peritoneal
dialysis system.

 Figure 149:
Henry Tenckhoff

Washington to continue Boen's work. Tenckhoff quickly realized that the peritoneal dialysis procedure would have to be changed if the program was to grow. His first objective was to find a peritoneal dialysis delivery system that would be easier to use. Patients had a great deal of difficulty handling the large 40-liter bottles. In addition, it was very time consuming to prepare and sterilize the great quantities of water required. And there was always a long waiting period before dialysis so that the fluid could be heated to the proper temperature.

Tenckhoff's first step in simplifying the system was to eliminate the need to transport the 40-liter bottles. This was accomplished by instilling a water still in the patient's house to provide sterile water (Figure 150). The water was mixed with a peritoneal concentrate to provide the proper dialyzing fluid. Tenckhoff's group also developed a solenoid system that would automatically fill and empty the peritoneum.

The system worked, but it remained cumbersome and time consuming and, in some cases, it was dangerous because of the high pressures involved in the use of the still.

Their next approach, in 1969, was to use an inline "reverse osmosis" (R/O) water purification system to eliminate the need for the large bottles and the still.⁶⁸ The R/O water was mixed with the peritoneal concentrate, and an integrated solenoid controller related the inflow and outflow of the peritoneal solution (Figure 151). Tenckhoff integrated the R/O system into a simplified automatic peritoneal dialysis machine, and the system became the prototype for all the R/O peritoneal machines that were developed later. Tenckhoff now had a system that could be operated easily and effectively by the patient at home.

Figure 150:
Home peritoneal dialysis system designed to produce sterile fluid and to automatically mix with a peritoneal

Figure 151:
Prototype of 'reverse osmosis' peritoneal dialysis machines developed by Henry Tenckhoff.

Russell Palmer - Development of a Catheter for Long-Term Use

Russell Palmer (Figure 152) had been one of the first to do hemodialysis in North America using the rotating drum kidney in 1946. In 1962, Palmer began looking for a dialysis procedure that did not have the problems associated with hemodialysis. His focus was on developing a peritoneal catheter for long-term use.

Because Palmer had been aware of the excellent work of Wayne Quinton in developing the silicone arteriovenous (AV) shunt for chronic hemodialysis, he asked Quinton to develop a silicone catheter that could be left in the abdomen permanently. The catheter they developed sealed properly at the exit site and prevented bacteria from migrating to the peritoneal cavity. Their pioneering effort was a significant step forward in the development of chronic peritoneal dialysis because it provided continuous access to the peritoneum for the first time (Figure 153).⁶⁹

Tenckhoff saw the value of Palmer's concept, and he began to look at ways to modify the catheter so that it would be easier to insert and use.⁷⁰ He shortened the catheter and suggested two designs, straight and curled. In addition, he added Dacron felt cuffs to help seal the openings through the peritoneum (Figure 154, Figure 154a). He also developed an insertion tool, called a trocar, that was designed to provide easy placement of the catheter. Tenckhoff now had a complete system for doing chronic intermittent peritoneal dialysis.

Figure 152:
Russell Palmer, M.D.

Figure 153:
First Chronic peritoneal catheter made from silicone rubber. Developed by Russell Palmer and Wayne Quinton.

Figure 154:
Tenckhoff catheters, with Dacron cuffs

Figure 154:
Tenckhoff catheters, with Dacron cuffs

Norman Lasker - The "Peritoneal Cycler"

Norman Lasker's interest in treating renal failure was stimulated by his experience at the Georgetown University School of Medicine in 1961.⁷¹ Harold Jekhers, Chairman of the Department of Medicine, arranged for Lasker (Figure 155) to spend a period of time with George Schreiner to learn to do hemodialysis and to gain experience in clinical nephrology. Lasker developed a keen interest in renal care, particularly dialysis. After his training was completed, he accepted the position of Acting Director of the Renal Division at the Seton Hall College of Medicine in New Jersey.

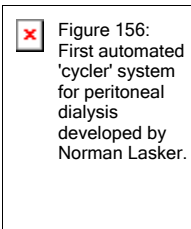
Funding for dialysis was difficult to obtain in the 1960's and, as a result, there were few facilities for the care of dialysis patients. Thus, Lasker looked for other methods to treat patients in renal failure - ultimately adapting the techniques of Boen, Tenckhoff, and Palmer in establishing his peritoneal program.

Lasker had visited the Seattle program and had seen the automated systems developed by Tenckhoff, but he felt that these systems would be too expensive and too difficult for his group to manage on their own. He

Figure 155:
Norman Lasker, M.D.

recognized that these devices were a great advance over the manual methods, but he was still fascinated by the possibility of developing a simple gravity-fed system.

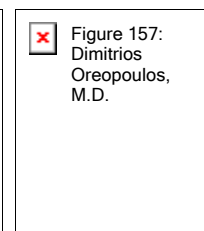
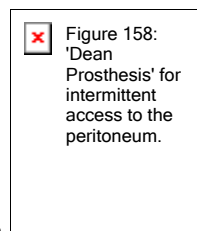
Fortunately in 1961, Lasker was approached by Ira Gottscho, a businessman who had set up a foundation in memory of his daughter Carol, who had died of kidney disease. When Lasker asked for help in developing a gravity-fed peritoneal dialysis delivery system, Mark Schachter, an engineer with the Gottscho Packaging Equipment Co., was assigned to help him design a mechanical system for peritoneal dialysis. The system which was designed to use 2-liter bottles and flexible plastic reservoir bags, was safe, easy to set up, and easy to operate. Two important features included in the system were the ability to measure the volume of fluid to be instilled into the peritoneal cavity and the ability to warm the solution before the "fill" cycle. Lasker called his system the "peritoneal cycler" ([Figure 156](#)).



When Lasker moved to the Thomas Jefferson School of Medicine in Philadelphia, in 1967, he again found that there were no funds available for in-center dialysis and that the state would only support home dialysis. He felt that the hemodialysis equipment available at the time was too expansive and difficult to use for most home patients. So he began to send patients home on the "cycler" as early as 1970. The medical community did not readily accept the device because of a bias against peritoneal dialysis, but this attitude did not diminish Lasker's enthusiasm; he was convinced that an automated peritoneal dialysis system had a place in treating the home dialysis patient.

Dimitrios Oreopoulos - Development of the IPD System

Dimitrios Oreopoulos ([Figure 157](#)), who was educated in Greece, had been introduced to peritoneal dialysis during his medical training in Belfast, Ireland in 1966. Oreopoulos noticed that researchers were having their greatest difficulties with the catheter. Norman Dean, a physician from New York City, had shown him a simplified technique for inserting a catheter using the "Dean Prosthesis" ([Figure 158](#)); this technique allowed the access site to be used over and over again. Following his meeting with Dean, Oreopoulos began to put patients on chronic peritoneal dialysis using Dean's technique. In June, 1969, Oreopoulos accepted a position at the Toronto Western Hospital, where he was put in charge of a four-bed intermittent peritoneal dialysis (IPD) program.



Stanley Fenton, of Toronto, had visited the University of Washington to observe their chronic peritoneal dialysis program in late 1960, and he was impressed with the results that were being obtained with the Tenckhoff catheter.

On his return to Toronto, he met with Oreopoulos, and they decided to use the Tenckhoff catheter as their access device and to adapt Tenckhoff's technique. Because of space limitations at the Toronto Western Hospital, they began sending patients home on intermittent peritoneal dialysis.

Oreopoulos had heard about the "Lasker cycler," and he visited Philadelphia to see how well it worked. He was so impressed with its simplicity and economy, he ordered several units and began to use them for home patients.

By 1974, Oreopoulos was managing more than 70 patients on intermittent peritoneal dialysis - the largest program devoted exclusively to peritoneal dialysis at that time.

The Development of CAPD

Jack Moncrief and Robert Popovich - Development of Continuous Ambulatory Peritoneal Dialysis

Legislation passed in 1972 provided funding for all patients who required dialysis treatment. This "financial milestone" made possible the treatment of large numbers of patients. In 1970, 5 000 patients were using some form of dialysis treatment worldwide. By 1980, that number had grown to 150 000 patients, with the number expected to increase by about 10 000 per year.

Jack Moncrief had finished a residency in nephrology at Georgetown University and had set up his practice in Austin, Texas. In 1970, he received a grant from the Texas Rehabilitation Commission to open an in-center dialysis program. The patient population grew very rapidly, and it was evident that the community's needs still were not being met. A new facility was built at the Austin Diagnostic Clinic in 1973 to accommodate the increased number of patients who were now eligible for care.

In 1975, Peter Pilcher was accepted for chronic dialysis at the Austin Diagnostic Clinic. A standard A/V fistula was created and dialysis was attempted with the same result; the fistula would not function. It became

obvious that although Pilcher required dialysis, he was not a candidate for hemodialysis.

Because Peritoneal dialysis was not available in Austin, the staff suggested to Pilcher that he move to Dallas where he could be placed in an IPD unit and given the 60 hours of treatment per week he required. Pilcher refused to move to Dallas, and hope diminished for his survival.

The Staff at the Austin Clinic was determined not to let their patient die; they decided that the only solution was to find a way to treat him with peritoneal dialysis.

Robert Popovich, a biomedical engineer at the University of Texas, worked out the kinetics of "long dwell equilibrated peritoneal dialysis." 72

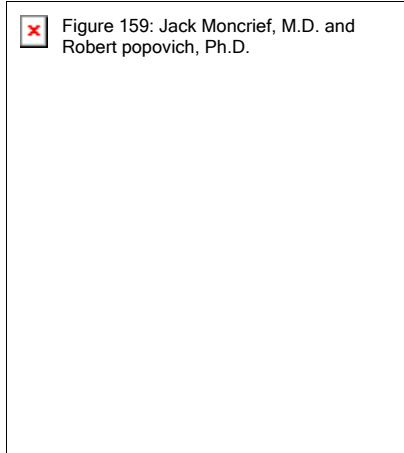
Popovich and his associates determined that five exchanges of 2 liters per day would achieve the appropriate chemistries, and that they needed to remove 12 liters of equilibrated solution from the patient each day.

Moncrief and Popovich ([Figure 159](#)) used a standard 2-liter bottle and attached a simple piece of tubing to it, along with a Tenckhoff catheter. Fluid was instilled for a period of four hours and then drained out. The procedure, which they called Continuous Ambulatory Peritoneal Dialysis (CAPD), allowed them to control successfully and simply a patient's chemistries and fluid removal. The only shortcomings of the technique were potential complications of infection and protein loss.

Moncrief noted that the protein loss was observed very early in the treatment series, and it became evident that the diet of the patient would have to be supplemented with protein, while other dietary restrictions could be relaxed.

Once Moncrief determined that the solution could be left in the peritoneum overnight without compromising the patient, Peter Pilcher was trained to do the exchanges by himself. He dialyzed using CAPD for more than two months and then received a kidney transplant.

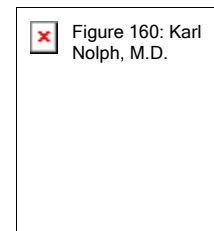
The Austin group was so impressed with Pilcher's results, they requested a grant from the National Institute of Health to allow them to continue dialyzing patients with CAPD - a procedure that was not covered by Medicare.



Karl Nolph - Verification of the Efficacy of CAPD

Karl Nolph ([Figure 160](#)), at the University of Missouri, had an interest in the kinetics and transport of the peritoneum and was aware of the Austin group's work. He was asked by the National Institute of Health to join the group and evaluate the clinical use of CAPD.

Nolph began to treat patients with CAPD in January 1977. The results, which did get published this time, were promising, but the high incidence of peritonitis continued to be a problem.



Oreopoulos's First CAPD Patient

Oreopoulos was skeptical of the clinical application of CAPD. Fortunately, Jack Rubin, a former rotating resident of Toronto Western, had worked with the University of Missouri on the CAPD program. On a visit to Toronto, he told Oreopoulos of the results of the CAPD program at the University of Missouri and noted the therapeutic benefit of CAPD.

He also pointed out the problems they were having with peritonitis and the fact that the source of infection appeared to be related to the use of the bottles.

In 1977, one of Oreopoulos's patients, who had been trained on R/O peritoneal dialysis but was not doing well on it, was readmitted to the hospital to be trained on the cyclor. When the patient fell in the hospital and could not be readily moved to the area where she was normally treated, the staff decided to perform emergency manual peritoneal dialysis on her.

In Canada, 2-liter collapsible containers of peritoneal solution had just begun to be used. The staff used a standard "Y" tubing set with the 2-liter container and began to perform the standard CAPD procedure. The bag that had been used to instill solution in the patient was retained and then used to collect the spent solution. The procedure was repeated every four hours. The patient's condition improved dramatically.

When Oreopoulos wanted to improve the fit of the tubing into the bag and into the catheter, he consulted with Ron Hamade, his local Baxter representative. Oreopoulos asked him to find a piece of tubing that had a spike on one end (to fit into the bag) and a male press fitting on the other (to fit into the catheter). Hamade suggested that they use a piece of the tubing used on the R/O set. The new system, which was less cumbersome

for the patient than the "Y" set used previously, worked perfectly - providing a tighter, more secure fit that greatly reduced the chances of infection.

Oreopoulos was able to convert his IPD patients quite rapidly to CAPD, and because he had a large number of patients, he could evaluate the results in a broad-based patient population very quickly. He was able to compare the use of peritoneal solution in a bag to a bottle - observing the ease of use, as well as the effect of the closed system in controlling infection.

Interest in CAPD continued to grow during the 1970's, but it became apparent that if the peritonitis could not be better controlled, CAPD did not have a future. Efforts in the United States centered on gaining FDA approval for the 2-liter container so that the closed system advantage could be realized ([Figure 161](#)). That approval was received in 1978.

In 1979, Baxter released the first complete CAPD system, which included dialysis solution in three dextrose concentrations for controlling ultra filtration, a solution transfer set and a "prep kit" to help control infection at the bag-spike connection.

If it is the obligation of science and industry not only to lengthen the life of a kidney patient, but to rehabilitate them physically, psychologically, and economically, so that his life is as full as possible, CAPD may be the closest we have come yet. CAPD takes place on a continuous 7-days-a-week, 24-hour-a-day basis. This self-administered form of dialysis offers the advantages of mobility, simplicity, independence from the hospital or center and, potentially, an improved lifestyle for the patient ([Figure 162](#)).

CAPD is well suited to home use and does not cause large fluctuations in the amount of fluid retained by the body. This, in turn, may reduce stress on the heart and blood vessels, thereby controlling blood pressure. It has fewer dietary restrictions and can be used where there is no electricity or skilled assistant. It has great potential for rural, isolated, and third-world people with kidney failure.

In 1983, Medicare legislation provided for the same reimbursement for dialysis regardless of whether it was given at home or as in-center treatment. This is called the "composite rate." This action further stimulated the use of home training programs using CAPD.

CAPD for Diabetics

Initially, patients with diabetes were precluded from being treated with dialysis because of complications aspects of the disease. Carl Kjellstrand, at the University of Minnesota, appears to be the first researcher to suggest that insulin could be introduced into the peritoneum - during the regular peritoneal exchanges - to help control diabetes.⁷³

This technique, offered in 1971, was not adopted, probably because the 30-minute dwell times that Kjellstrand used for intermittent peritoneal dialysis were too short to allow for adequate diffusion of insulin into the patient. In time, however, his idea was modified by others who also was the potential for the intraperitoneal administration of insulin.

C. T. Flynn's work in this area was particularly significant.⁷⁴ In 1979, he proposed that renal failure patients with diabetes might do better on CAPD.


It was Flynn's contention that CAPD's long dwell time for dialysis fluid in the peritoneal cavity made it appropriate as a medium for insulin administration. Because of its large molecular structure (5000MW), insulin is slowly absorbed from the peritoneum. Thus, by incorporating insulin into the CAPD procedure, Flynn was able to maintain blood sugars in the normal range required for good patient management.


Currently, more than 30% of the patients on peritoneal dialysis are diabetic. In fact, intraperitoneal insulin administration has become an important technique in treating the diabetic complications of renal disease.


Recent Modifications in Peritoneal Dialysis


The basic CAPD procedure has been further modified to help control peritonitis. Ultraviolet treatment of the bag-spike junction helps prevent contamination during the exchange procedure ([Figure 163](#)). Modification of container sizes and formulations has further expanded the efficiency of the system ([Figure 164](#)). Recent developments allow the patient to remove the collapsed container between exchanges rather than keeping it attached and rolled up at the waist - further accommodating patients' lifestyle requirements.


One other variation on peritoneal dialysis is the use

 Figure 161: CAPD Closed System.

 Figure 162: CAPD offers dialysis patients mobility, simplicity, and independence.

 Figure 164: CAPD system, with container and titanium adapter.

 Figure 163: UV-XD exchange device.

 Figure 165: PAC-X

of the automated cyclor ([Figure 165](#)), which allows patients to sleep during the night while the cyclor automatically performs the necessary exchanges, monitoring the inflow of solution, the "dwell" time, and the drain time. Automated peritoneal dialysis (APD) accommodates the needs of pediatric patients, patients who cannot do the normal CAPD procedure, and those with busy daytime schedules who want to free up their daytime hours

The Future

The genesis and evolution of the artificial kidney is a story of the kinds of challenges that only the human body can issue ... and the kinds of creative solutions that only the human mind could devise. It is the story of dedicated scientists in the medical community, academia, and in industry who have tried and are continuing to try to provide the quality of care that will minimize the burden of those who have kidney disease.

Dialysis has indeed come a long way from the hot baths of Rome. But scientists are not satisfied yet. They would like to overcome the complications of anemia common to patients with renal failure; control fluctuations in chemical and fluid balance that affect the patient's sense of well-being; decrease the duration of the procedure even more - while maintaining its efficiency. They would like to prevent the cardiovascular complications prevalent in dialysis patients. And they would like to better understand the causes of kidney disease and how it can be prevented.

They foresee refinements in vessel access for both hemodialysis and peritoneal dialysis, dialyzers for special patients and, ultimately, an effective, practical, wearable artificial kidney.

The challenge of adequate dialysis continues.

References

- 50. An eighteenth century suggestion for peritoneal dialysis. An editorial. *Internatl J Artif Organs* v 3(2):67-68, 1980.
- 51. Wegner, G. Surgical comments on peritoneal cavity with special emphasis on ovariectomy. *Arch f Klin Chir* v 20:53-145, 1877.
- 52. Starling, E. H. and Tubby, A. H. On the paths of absorption from the peritoneal cavity. *J Physiol* v 16:140, 1894.
- 53. Orlow, W. N. Some studies of the absorption of the abdominal cavity. *Arch f Physiol* v 103:423-427, 1927.
- 54. Engel, D. Uber die ausspulbarkeit von toxin, antikorpem und artfremden eiweis durch des lebende peritoneum. [The rinsability of toxin, antibody and foreign protein through the living peritoneum.] *Centralbl f Bacteriologie* v 103:423-427, 1927.
- 55. Rosenberg, M. Uber stickstoffhaltige retentionsstoffe im blute und in anderen korpeflussigkeiten bei nephritikern. [Nitrogenous retention of substances in blood and in other body fluids in the core of the kidneys.] *Berl Klin Wochenschr* v 53:548-565, 1923
- 56. Putnam, T. The living peritoneum as a dialyzing membrane. *Am J Physiol* v 3:548-565, 1923.
- 57. Ganter, G. About the elimination of poisonous substances from the blood by dialysis. *Munch Med Wchenschr* v 70:1478-1480, 1923.
- 58. Rosenak, S. and Siwon P. Experimentelle untersuchungen uber die peritoneale ausscheidung harnpflichtiger substanzen aus dem blute. [Experimental investigation of the peritoneal clearance of urea-bound substances from the blood.] *mitt grenzgeb Med Chir* v 39:391-408, 1926
- 59. Wear, J. B., Sisk, I. R., and Trinkle, A. J. Peritoneal lavage in the treatment of uremia. *J Urol* v 39:53-62, 1938
- 60. Kolff, W. J. *New ways to treating uremia*. J.A. Churchill Ltd. London, pp. 91-97, 1947.
- 61. Frank, H., Seligman, A., and Fine, J. Treatment of uremia after acute renal failure by peritoneal irrigation. *JAMA* v 130:703-705, 1946.
- 62. Grollman, A., Turner, L.B., and McLean J. A. Intermittent peritoneal lavage in nephrectomized dogs and its applicati9on to the human being. *Arch Intern Med* v 87:376-390, 1951.
- 63. Maxwell, M. H., Rockney R. E., and Kleeman, C. R. Peritoneal dialysis, techniques and application. *JAMA* v 170:917-924, 1959.
- 64. Doolan, P. D., Murphy Jr., W. P. Wiggins, R. A., et al. An evaluation of intermittent peritoneal lavage. *Am J Med* v 26:831-844, 1959
- 65. Ruben, R. E., Lewis, A. E., and Hassid, E. *The use of peritoneal dialysis in a patient with chronic renal insufficiency*. An unpublished paper. 1960.
- 66. Boen, S. T. *Peritoneal dialysis*. Van Gorcum & Comp N.V. Asterdam, 26, 1959.
- 67. Boen, S. T., Mion, C. M., Curtis, F. K., et al. Periodic peritoneal dialysis using repeated puncture

- technique and automatic cycling machine. *Trans Am Soc Artif Intern Organs* v 10:409-414, 1964.
- 68. Tenckhoff, H., Meston B., and Shilipeater G. A simplified automatic peritoneal dialysis system. *Trans Am Soc Artif Intern Organs* v 17:436-439, 1972.
 - 69. Palmer R. A., Quinton W. E., and Gray, J. E. Prolonged peritoneal dialysis for chronic renal failure. *Lancet* v 1:700-702, 1964.
 - 70. Tenckhoff, H. and Schecter, H. A bacteriologically safe peritoneal access device. *Trans Am Soc Artif Intern Organs* v 14:181-183, 1968.
 - 71. Lasker, N., McCauley, E. P., and Passarotti, C. T. Chronic peritoneal dialysis. *Trans Am Soc Artif Intern Organs* v 12:94-105, 1966
 - 72. Popovich, R. P., Moncrief, J. W., Nolph, K.D., et al. Continuous ambulatory peritoneal dialysis. *Ann Intern Med* v 88:449, 1978.
 - 73. crossley, K. and Kjellstrand, C. M. Intraperitoneal insuling for control of blood surgar in diabetic patients during peritoneal dialysis. *Br Med J* v 1:269-270, 1971
 - 74. Flynn, C. T. and Nanson, J. A. Intraperitoneal insulin with CAPD - an artificial pancreas. *Trans Am Soc Artif Intern Organs* v 25:114-117, 1979.

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