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Chapter 1

Introductory Chapter: Peritoneal Dialysis, Overview and Current Concepts

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1. Historical perspective

Understanding the evolution of the peritoneal dialysis technique we use today is useful in enhancing the successes and reducing the failures we still face with this most common form of home dialysis empowering the patient to be in control of his own end-stage renal disease management. This chapter cannot mention all the early heroes who advanced this technology. I have had the good fortune of working with several of these individuals in my 48 years of study and practice of nephrology. I present this review emphasizing those with whom I worked or shared their experience at conferences and seminars.

The first clinical reports of a technique which we would recognize today as peritoneal dialysis was based on the care provided by George Carter in Germany in 1923 [1]. He instilled 1–3 L of sterile electrolyte-containing fluid with dextrose added for fluid removal into the abdomen by a needle. He drained it by a rubber hose into bottles. He had sterilized his tubing and bottles by boiling water. He used a 30-min dwell and demonstrated improved blood chemistries.

In 1936, the first patient who survived acute obstructive renal failure by peritoneal dialysis until recovery was described by Wear et al. [2]. The first series of patients reported success in the peritoneal dialysis of 10 of 21 patients by Kolff [3]. I had the honor of working side by side with Dr. Kolff years later at the University of Utah where he had established an Artificial Organs Institute. They used a glass catheter, rubber tubing, and porcelain containers all of which were able to be sterilized for repeat usage. Morton Maxwell reported the successful dialysis of patients using a flexible polyethylene catheter with side holes for drainage. He instilled 2 L into the peritoneum, let it dwell for 30 min, and then drained it back to the same bottles by gravity using the kind of tubing we recognize today [4]. This system was found to be simple to initiate in any patient, had the fewest numbers of connections to have periodically changed, and became quickly commercially available.

The problem with early peritoneal dialysis was that the tube was semirigid and required direct percutaneous placement with a trochar. If a patient was conscious, was normal in size and nutritional status, and could cooperate by tensing the rectus muscles, the trochar could be placed more easily. If the patient was small, thin, or malnourished, the indentation of the abdominal wall by the trochar risked penetration or perforation of intraabdominal structures. Thus, establishing the access to the peritoneal cavity was the first problem we encountered in using peritoneal dialysis as much as we did in the 1960s and 1970s due to the lack of wide availability of hemodialysis equipment and trained staff. Other uses of peritoneal catheters besides dialysis soon followed, including treatment of hypothermia [5] and diagnostic peritoneal lavage for intraabdominal bleeding or for proof of peritonitis.

The placement of the catheter became easier and more accurate with several modifications in technique. Instead of direct puncture through the intact skin, it became clear that a small scalpel incision in the midline raphe and limited blunt dissection to the parietal peritoneal membrane made the insertion less of a risk of intraabdominal penetrations. Then, Ash popularized a small peritoneal scope over which the catheter was placed to guide it internally into a paracolic space that was free of adhesions. Initially, it was used for acute renal failure with the more rigid catheters, but later its use included placing the more flexible catheters used for long-term dialysis to be described below [6, 7]. Finally, the use of a guidewire and dilator before the catheter was placed with the trochar or scope made the process safer and easier to establish acute peritoneal access with a high probability of effective flow and drainage.

Tenckhoff and Schechter [8] contributed to the development and widespread use of a double-cuffed very pliable catheter which launched the ability of patients to have a catheter in place indefinitely with low risk of infection. The cuffs allowed tissue growth into the mesh to create a seal. The pliability made the catheter conform to the paracolic gutter so as to bend with the patient allowing the patient to be comfortable and mobile. Today, chronic catheters are most often placed by surgeons during conventional laparoscopy, but some still do open procedures. These techniques will be reviewed in a subsequent chapter in this book. There still are problems with pain after catheter insertion due to migration from the original location, plugging of the drainage ports by omentum, and discomfort depending on the location of the exit site in relation to the umbilicus or belt line. Catheter extensions can be used to allow the exit sites to be moved more superiorly. Such a strategy is often helpful if a large pannus is present.

Popovich et al. [9] expanded the use of peritoneal dialysis as it morphed into the most convenient form of home dialysis. They were among the earliest to report the largest number of patients being maintained on chronic home peritoneal dialysis, often continuous ambulatory peritoneal dialysis (CAPD). Later, improved automation of the delivery, dwell, and drainage of solutions by what has become known as a "cycler" has now become the preferred technique of home peritoneal dialysis at least in part due to the need for only one connection per day at night and one disconnection in the morning. The reduction of manipulation of the catheter reduces contamination and infection and is less time-consuming to the patient. The development of the "cycler" has been attributed to a variety of pioneers including Lasker [9].

Solute removal and ultrafiltration assessment are mandated to be measured periodically to assess the quality of care delivered by home peritoneal dialysis. Twardowdki has been credited

with assisting in the development of the peritoneal equilibration test (PET) to assess transport characteristics of a patient's peritoneal membrane [10]. Briefly, the PET test assists in managing fluid removal strategies of a patient by manipulating dwell time. Survival of patients with end-stage renal disease has been shown to be better associated with effective ultrafiltration rather than solute removal [11].

While in training, I noticed that fluid removal by acute peritoneal dialysis was always less efficient at the time of initiation compared to hours later after many repetitions of hourly cycles of instillation, dwell, and then the drainage of the fluid. Negative fluid balance with more out than in per cycle got easier as the cycles accumulated. Later, it became clear to me that the difference lays in the osmotic gradient of dextrose vs. the osmotic effect of nitrogenous toxins which decreased over time as their concentration reduced over time due to diffusion during each successive cycle. For chronic peritoneal dialysis, the efficiency or ultrafiltration is a function of using different concentrations of dextrose alone or in combination over the period of consecutive cycles. Using 1.5, 2.5, and 4.5% dextrose solutions to fill the peritoneal cavity with a usual amount of 2000 cc, progressively more fluid returns are usually seen. The difference represents the net ultrafiltration. One common and annoying problem occurs when drainage is unexpectedly low. The impact is that the patient's net dialysis and ultrafiltration will be impaired. To solve the problem, evaluation of the location and function of the catheter, health of the peritoneal membrane, and hemodynamic and volume status of the patient are needed. If the patient is hypovolemic or hypotensive, blood may be shunted from the viscera leading to reduced membrane function transport.

Icodextrin was developed to assist with problem cases of inadequate ultrafiltration in some patients. It is nonabsorbable carbohydrate which exerts a long duration osmotic effect. It is added as an afternoon long swell exchange [12]. This intervention is useful when the membrane is not functioning normally, when patients have very low urine volumes, need more dialytic fluid removal, or cannot tolerate the glucose load of the usual peritoneal dialysis solutions.

Oreopoulos is credited with simplifying peritoneal dialysis by the introduction of lightweight bags of solutions, y-tubing, and automated cycling. He put it all together and reported on a growing cohort of patients performing chronic peritoneal dialysis at home. He therefore suggested the idea that this strategy be considered as the first choice in initiating end-stage renal disease management [13].

Ultrafiltration efforts are monitored monthly by dialysis centers. The PET referenced above tests the speed of diffusion of glucose from the peritoneal solutions to the patient. In this way patients are described as fast transporters or slow transporters. Since the glucose determines the osmotic gradient for ultrafiltration, the dwell time has to be tailored to the individual patient depending on their transport characteristics. Short dwell times preserve the osmotic gradient in the fast transporters but shorten the time for other nitrogenous substances to be removed. More cycles are needed in some cases to meet these needs in a fast transporter. Slow transporters maintain ultrafiltration gradients throughout a long dwell but may need fewer exchanges because the prolonged dwell allows more nitrogenous solute diffusion. **Table 1** illustrates the variety of prescription adjustments depending upon PET results. Because of changes in the transport characteristics of the peritoneal membrane over time and after

Very fast transport	Excellent ultrafiltration	Poor solute diffusion	Short dwells	More cycles
Fast transport	Good ultrafiltration	Fair solute diffusion	Medium dwells	Variable cycles
Slow transport	Fair ultrafiltration	Good solute diffusion	Variable dwells	Medium cycles
Very slow transport	Poor ultrafiltration	Excellent solute removal	Long dwells	Less cycles

Table 1. PET test results.

1. Twenty-four-hour urine volume is needed—200 cc/24 hours
2. Measure the urine urea concentration—22.5 mg/dL
3. Measure the serum urea concentration—75 mg/dL
4. V is the total body water—60 kg × 60% water = 36 L
5. kT/V for residual renal function therefore is 22.5 × 2 (convert ml to dL)/75 = 0.533 mL/min × 1440 min/day 0.767 L/day divided by 36 L = 0.02 L per day of kT/V × 7 days = 0.14 total kT/V from residual function
6. Twenty-four-hour collection of peritoneal drainage is needed—10 L
7. Measure the peritoneal urea concentration—70 mg/dL
8. The fluid/plasma urea (D/P ratio) is calculated—70/75 = .93. The kT of urea is .93 × 10 L of drainage = 9.3.
9. V is the total body water—36 L
10. kT/V per day for dialysis therefore is 9.3/36 = .258 per day. kT/V per week from dialysis is .258 × 7 = 1.8
11. Total kT/V is that for dialysis plus residual renal function—1.8 + 0.14
12. Total kT/V therefore is 1.94
13. The goal is total kT/V per week >1.7

Table 2. Calculation of kT/V in 60 kg women.

episodes of peritonitis, it is recommended that peritoneal equilibration testing (PET) be repeated periodically in a given patient.

Solute removal adequacy is monitored closely by centers for home dialysis. Adequacy is assessed by the term kT/V which was first developed by Gotch to assess urea kinetics in hemodialysis patients but later applied to patients receiving peritoneal dialysis [14]. Total kT/V is determined from the peritoneal dialysis urea clearance per week plus the contribution of the patient's own renal function. **Table 2** illustrates the calculation of kT/V in a 60 kg patient. Total and dialytic kT/V is monitored monthly by dialysis centers, and the dialysis prescription is adjusted accordingly if necessary. If there is a high residual renal function, the kT/V of the dialysis can be reduced, for example. As time progresses, it can be adjusted upwards.

Tidal dialysis [15] was developed as an additional strategy for additional solute removal with a comfortable small amount of peritoneal fluid after the evening cycles are completed. It has also been used to allow a volume to serve as an aqueous cushion to keep the catheter from abutting on internal structures to cause irritation and pain. I mention it here only for completeness in the historical evolution of the concepts used by centers in managing home peritoneal dialysis patients.

Infections remain a constant threat to the long-term success of home peritoneal dialysis [16]. Infections have been found to fall into three categories: initial, relapsing, and recurrent. Peritonitis vs. tunneled infections are the two possible locations for the brunt of consequences. The problem of managing various types of infections in peritoneal dialysis patients will be reviewed in a separate chapter in this book.

2. Future possibilities

In my observations as a nephrologist for nearly 50 years, I have witnessed the overwhelming trend in the evolution of dialysis technology to miniaturization and increased efficiency. The large tanks of dialysate have been replaced by efficient pumps of water sources either from pipes or bags. The large parallel plates of dialyzers have been replaced by small cylinders of hollow fibers. In some cases, sorbsystems allowed recirculation of small volumes of dialysate. So with peritoneal dialysis, the future will likely continue in this fashion. There will be continued miniaturization of products to increase efficiency. I envision smaller volumes of solution mixed with sorbents to allow more efficient diffusion and ultrafiltration driven internally by much smaller pumps approaching the size of insulin pumps or pacemakers running on long-term atomic batteries. Likely, the solutions will need to be refreshed much less often, perhaps once a week or even longer. The portals into the body will become smaller and smaller, perhaps ultimately the size of medium-gauged needles.

3. Summary

My first recollection of the problems faced with peritoneal dialysis included placing the catheter in the first place. Secondly, I felt we faced problem with drainage. Thirdly, we faced infections. Finally, we faced adequacy and fluid balance problems. These initial problems have continued as ongoing problems today. In addition they form the basis for monthly reporting of quality measures, although additional measures are also being monitored today. In this book the chapters address current issues which not surprisingly mirror the problems faced in the evolution of peritoneal dialysis and home dialysis.

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