Chapter 14
Peritoneal Dialysis Access and Exit-Site Care Including Surgical Aspects

P. Kathuria, Z.J. Twardowski, and W.K. Nichols

The key to a successful peritoneal dialysis program is a permanent and safe access to the peritoneal cavity. The catheter should provide optimal and consistent hydraulic function and form a stable interface with the body. A well-healed peritoneal dialysis catheter prevents the periluminal migration of bacteria and leakage of dialysate.

Peritoneal access is an important key point in technique survival. Catheter-related problems and infections cause up to 20% of patients to transfer permanently to hemodialysis; many more require temporary periods on hemodialysis [1]. With the reduction in peritonitis rates, catheter-related complications during peritoneal dialysis have become a major concern.

The history of peritoneal access, different peritoneal dialysis catheters, surgical insertion techniques, infections, and mechanical problems are addressed in this chapter.

Glossary

The terminology pertinent to the currently used peritoneal catheters is reviewed here [2]. After implantation the typical double-cuff catheter has three segments (Fig. 14.1): *intraperitoneal,* located intraperitoneally; *intramural,* contained within the abdominal wall tunnel; and *external,* situated outside of the skin exit. The *peritoneal catheter tunnel* is the passageway through the abdominal wall within which the peritoneal catheter is contained. A properly implanted double-cuff peritoneal catheter creates a tunnel with a short sinus tract, a shallow peritoneal recess, and a 5–7 cm long tunnel proper, which consists of tissue ingrown into the cuffs and a fibrous sheath covering the inter-cuff tunnel segment. A longer tunnel proper (20–50 cm) is typical for the presternal catheter [3]. Figure 14.2 depicts tissue structures in relation to cuff position in healed tunnels. After implantation of a single, deep cuff catheter, the tunnel is composed of three parts: 1) a sinus tract located between the skin exit and the cuff; 2) a peritoneal tunnel recess, which is a peritoneal pocket covered with the mesothelium from the internal tunnel exit to the collagen-mesothelial interface at the cuff; and 3) a tunnel proper, comprising the tissue ingrown into the cuff. Another type of single-cuff catheter is provided only with a superficial cuff, has a short sinus tract, but a long peritoneal recess.

Historical Perspective

Both biologic and technologic evolutions reveal puzzling similarities. A structure of a new species is taken from the existing forms; new technological solutions develop from existing forms as well. In the early years of peritoneal dialysis, there was no specific device for peritoneal dialysis; rather, the devices used in medicine, general surgery, and urology were adapted [4]. A species or technology not adjusted to the environment or requirements is eliminated and is preserved in fossils or museums of technology.

In the older literature three terms were used for the infusion of fluid to and drainage from the peritoneal cavity: peritoneal lavage (from Latin *lavare* = to wash), irrigation, (from Latin *irrigare* = to water), and dialysis (from Greek *dialusis* = to separate). The terms *lavage* and *irrigation*, used frequently in the English literature in the 1930 s, 1940 s, and 1950 s, came from surgical practice of cleaning the peritoneum. *Peritoneal dialysis* indicates removal of toxins from the blood through the peritoneal membrane, and this term was commonly used in German literature in the 1920 s and 1930 s. Since the 1960s, it has been used almost exclusively for the process of toxin removal from the blood through the peritoneal membrane.

P. Kathuria (✉)
University of Oklahoma College of Medicine, Tulsa, Oklahoma
e-mail: Pranay-Kathuria@ouhsc.edu

R. Khanna, R.T. Krediet (eds.), *Nolph and Gokal's Textbook of Peritoneal Dialysis*,
DOI 10.1007/978-0-387-78939-2_14,

Fig. 14.1 Diagram of double-cuff Tenckhoff catheter showing three segments created after implantation

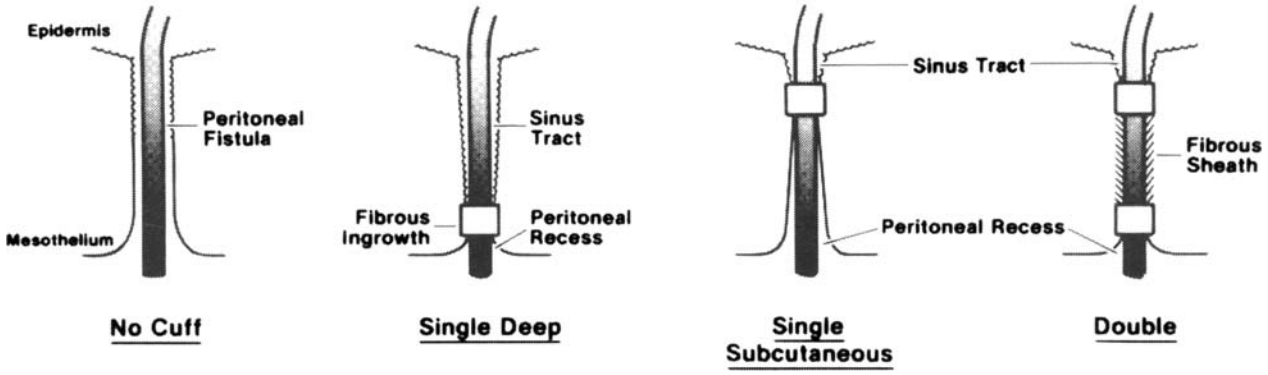

Fig. 14.2 Tissue structures in relation to cuff position in healed tunnels. In catheters without cuffs, a peritoneal fistula is formed. A single deep cuff creates a shallow peritoneal recess and a deep sinus tract predisposing to exit infection. A single subcutaneous cuff generates a shallow sinus tract and a deep peritoneal recess predisposing to pseudohernia. Properly positioned two cuffs limit the depth of both structures

In 1923, Ganter [5] reported his experience in animals and two patients. He used metal needles commonly used at that time for abdominal and pleural punctures. In patients, he did not drain the fluid as he did in guinea pigs, so it was not dialysis as we understand it now; however, there was some dialysis into the saline solution. Two years later at the meeting of the Polish Society of Biology, Landsberg and Gnoinski [6] presented the results of experiments in rabbits. After puncture of the peritoneal cavity with a trocar[1] in the epigastric region the peritoneum was filled with 1 L of Ringer's solution. After 15–30 min of equilibration, the peritoneum was drained through a puncture in the lower region. Because there was some dwell of the dialysis solution, their method should be called intermittent flow peritoneal dialysis in spite of the fact that two trocars were used. Rosenak and Siwon performed several experiments on continuous dialysis in nephrectomized dogs in 1926 [7]. They inserted two glass cannulas through laparotomy. The inflow cannula tip was placed below the liver, the outflow in the Douglas cavity. Simple glass tubes, used in early experiments, were frequently obstructed, so they decided to provide "cannulas with flask shape, multi-perforated, sprinkling can rose-like tips." If the cannula became obstructed despite this modification, they performed omentectomy before inserting new cannulas. One year later, Heusser and Werder carried out experiments on continuous flow peritoneal dialysis similar to those of Rosenak and Siwon. The inflow cannula was similar to theirs, but for outflow they used a rubber drain with multiple side perforations with the tip inserted into the small pelvis. "The omentum was creased with multiple sutures through the lower abdominal wound so that it could not block the openings in the drain tube" [8]. They speculated that the similar technique could be used in patients, and indeed they used it in three cases.

The first continuous flow peritoneal dialyses in humans with acute renal failure caused by poisoning with mercury bichloride were performed in two patients by Balázs and Rosenak in 1934 [9]. For peritoneal access they used glass cannulas distended globularly at the tip and having multiple holes (similar to those used previously by Rosenak and Siwon [7]) or cannulas made of fine wire. The inflow cannula was introduced between the liver and the diaphragm, the outflow cannula was inserted into the Douglas cavity. Both cannulas were introduced by laparotomy under local and light ethyl chlorine anesthesia. In the first patient the continuous dialysis lasted ½ h and 12 L of 4.2% glucose were used, in the second patient 19 L of 0.8% saline were used during 1½ h of continuous dialysis. Both patients died.

The first case of a patient who survived after peritoneal lavage for the treatment was reported by Wear et al. [10]. "A standard gall bladder trochar was introduced in the upper abdomen. The trochar introduced into the lower abdomen was modified by placing numerous small holes in the distal third to avoid occlusion of a single opening by the omentum and intestine. From an insulated reservoir the fluid was introduced into upper cannula. The lower cannula was attached to rubber tubing which hung dependent to a bottle on the floor and acted as syphon." The

[1] From French *trois* (three) + *carre* (side) = three-sided point, a sharp pointed instrument equipped with a cannula, used to puncture the wall of a body cavity and withdraw fluids.

authors used the procedure in five cases, but only one patient survived; it was unclear whether the patient was saved by peritoneal dialysis.

The first intermittent peritoneal dialyses in humans were performed by Rhoads in 1936 and 1937 [11]. In two patients thought to have acute renal failure, peritoneal lavage was performed. The fluid was introduced into the peritoneal cavity through a cannula introduced into the peritoneal cavity under local anesthesia. "Nine liters of fluid were introduced in 6 installments and a total of 6 ½ liters recovered." Temporary improvement in the patients' condition was noted; both patients ultimately died and autopsies revealed chronic glomerulonephritis. The author did not provide a detailed description of the cannula.

No papers on peritoneal lavage, irrigation, or dialysis appeared during the time of Word War II, but the number of renal failure cases after war trauma must have accelerated research on renal replacement therapies and numerous papers on these topics were published in the second half on the 1940s [4].

Abbott and Shea carried out several experiments on dogs to evaluate the methods of peritoneal lavage and desirable solutions. As a result of these experiments, they determined that for removal of dialyzable substances the use of intermittent injection and withdrawal of solution is more efficient than continuous flow lavage, and that the solution should have a chemical composition similar to that of interstitial fluid and should be made slightly hypertonic by the addition of small amounts of dextrose or gelatin or pectin. They performed a limited number of treatments in humans and concluded "that the withdrawal of the fluid could be best accomplished by the use of trochar or insertion of a rubber catheter, since the insertion of a needle does not, as a rule, permit a complete recovery of the injected fluid" [12].

Seligman, Frank, and Fine performed a series of experiments on nephrectomized dogs to determine suitable peritoneal access, optimal flow of continuous flow peritoneal irrigation, and proper irrigation fluid. The access was a mushroom-tip[2] type catheter inserted through an incision or a whistle-tip[3] type inserted using a trocar. Both types had added perforations. Mushroom-type catheters drained more effectively than the whistle-tip type catheters. "To help maintain patency of the irrigating catheters in long term experiments, omentectomy was performed . . . at the time of nephrectomy" [13]. The same group of authors reported the use of this method for treatment of four patients [14]. In all cases, a continuous flow method was used. Initially, the inlet tube was a catheter or a perforated small stainless steel tube. The outlet tube was a whistle-tip type catheter. In later cases, they used two mushroom catheters for inflow and outflow and ultimately they used a mushroom catheter for inflow and a stainless steel surgical drain tube for outflow (Fig. 14.3). The tubes were inserted through surgical incisions and held in place with subcutaneous staysutures. As prophylaxis against peritoneal contamination they incorporated a Mandler (Berkefeld) filter between the solution reservoir and a glass U-tube submerged in a water bath (40–45°C) and connected to the inflow tube. One patient with acute renal failure due to "parenchymatous injury to the kidneys from sulfathiazole administration" was also reported separately in more detail [15]. The mushroom catheter and the sump drain[4] were used in this case. During 7 days of peritoneal irrigation, solution flow ranged from 13 to 35 mL/min and urea peritoneal clearance ranged from 8.4 to 21.0 mL/min. The patient ultimately recovered kidney function. Although in the discussion the authors stated that "[w]e cannot state with finality that the patient would have died without peritoneal irrigation," the severity of the case, 15 days of oliguria/anuria, and improvement during peritoneal lavage seem to justify the assumption that *this was the first patient who survived because of peritoneal dialysis*. Weiss and Mills followed the experience of Frank, Seligman, and Fine using a mushroom catheter for fluid inflow and sump drain for outflow. To improve drainage the sump drain was inserted very low, just above the Poupart's ligament and passed down to the pelvis [16]. Reid, Penfold, and Jones referred to the Frank, Seligman, and Fine paper, but implemented a different technique. They used a Foley[5] catheter for infusion into the peritoneal cavity of twice-normal saline. They drained the fluid through the same catheter after the patient complained of abdominal distension and pain and the appearance of "obvious ascites." The infusion and drainage of fluid continued the following days, but they had difficulty with drainage through the catheter and a considerable amount of fluid leaked around the catheter [17]. Although they used a single catheter and drained the

[2] Mushroom or umbrella catheter, a self-retaining bladder catheter, was invented by de Pezzer in 19th century. It had no terminal opening, only lateral openings.

[3] Whistle-tip catheter = urethral catheter with a terminal opening as well as a lateral one.

[4] Sump drains were double-lumen tubes that allowed air to enter the drained area through the smaller lumen and displace the fluid into the larger lumen. The air sucked back through the larger tube helped to maintain its patency and prevented high negative pressure with consequent suction of adjacent structures into the openings of the large tube. They were used in general surgery and gynecology and in the intraperitoneal space for evacuation of fluid from the peritoneal cavity. The external tubes of sump drains were usually made of a network of stainless steel or brass cords; the internal tubes were solid cannulas.

[5] In 1929, Frederick E.B. Foley (1891–1966) developed a catheter for drainage of urine and retained in the bladder by the distensible balloon.

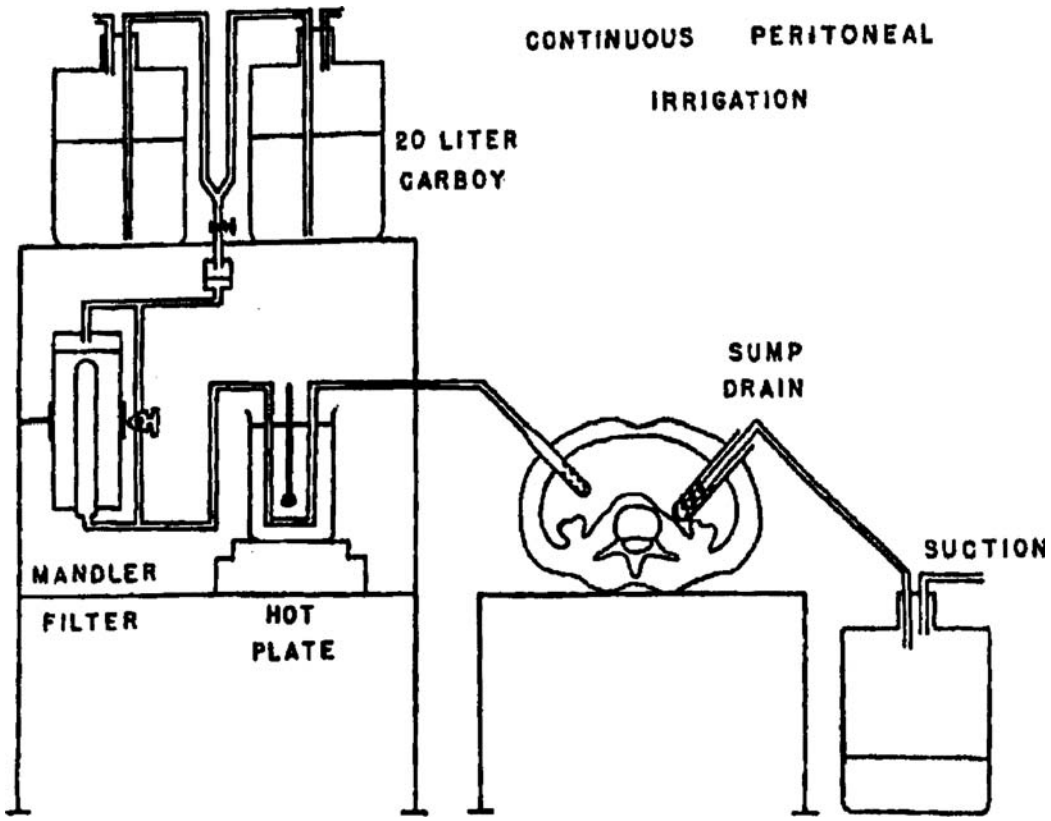

Fig. 14.3 Continuous peritoneal irrigation. A = 20 L carboy, B = Mandler filter, C = hot plate, D = rubber inflow catheter, E = sump drain, F = suction. Modified from [14]

fluid intermittently, the flow method was partly continuous because of constant leakage of fluid around the catheter. Ultimately, the patient recovered.

In 1947 and 1948 numerous papers appeared in the medical literature describing results with peritoneal irrigation [4]. The method of Frank, Seligman, and Fine was generally followed. The major problems encountered by clinicians treating patients with peritoneal irrigation were related to peritoneal access. Rosenak and Oppenheimer [18] listed the five most troublesome complications of peritoneal drains used for fluid outflow: "(1) Rigidity of the tube with resulting pressure on the intestines, (2) Constant suction of contaminated air into the peritoneal cavity, (3) Occasional plugging of the small openings, (4) Leakage of lavage fluid into the dressing, which is a potential source of infection and which make exact determination of nitrogen output difficult, (5) Difficulties of proper fixation of the tube on the abdominal wall." It may be added that fluid leakage made fluid balance very imprecise and resulted in extra nursing work. For the first time they developed a drain specifically for peritoneal dialysis. This was a modified sump drain. Made of stainless steel, the tube provided a rigid extra-abdominal portion, but flexible intraperitoneal portion made of a spiral, stainless steel spring wire with a rounded tip. An adjustable plate was screwed to the outer portion of the steel tube and served for fixation to the abdominal wall by means of adhesive plaster. Compared to the sump drain, the access introduced two important improvements: a flexible tube made of spiral wire instead of rigid pipe and the plate for fixation to the abdominal wall. A second version of the Rosenak-Oppenheimer access was described by Odel et al. [19]. The improved version had two accesses, one for inflow and one for outflow (Fig. 14.4). They were identical, except that the intra-abdominal part of the inflow tube was shorter that that of the outflow tube. The intra-abdominal portion of each tube was made of tightly coiled stainless steel with a rounded tip. Compared to the previous version with a rigid inner tube, in the new version both inflow and outflow accesses had an inner tube made of flexible rubber in the intra-abdominal portion.

In December 1948, Ferris and Odel published their experience with the Rosenak-Oppenheimer access [20]. They used it in only one case, and "found the inflow tube to be entirely satisfactory." However, they experienced considerable difficulty in fluid outflow, because the flexible steel spring appeared to be wound too tightly. They were also concerned with the foreign body reaction to metal and rubber tubes. Accordingly, they improved the Rosenak-Oppenheimer access by changing the intra-abdominal portion of the outer tube (Fig. 14.5). Instead of the spring

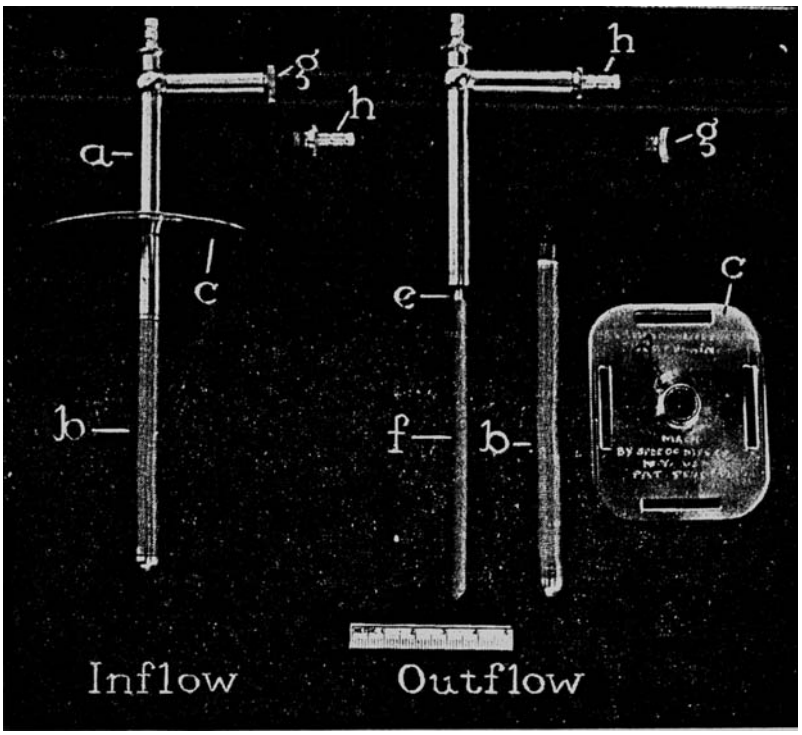

Fig. 14.4 Rosenak-Oppenheimer peritoneal tubes. A = rigid extra-abdominal, b = flexible intra-abdominal, c = malleable metal flange, d = thumbscrew, e = rigid inner portion, f = rubber inner portion, g = metal plug, h = adapter. The inflow tube on the left is assembled; the outflow tube on the right is partly disassembled. Modified from [19]

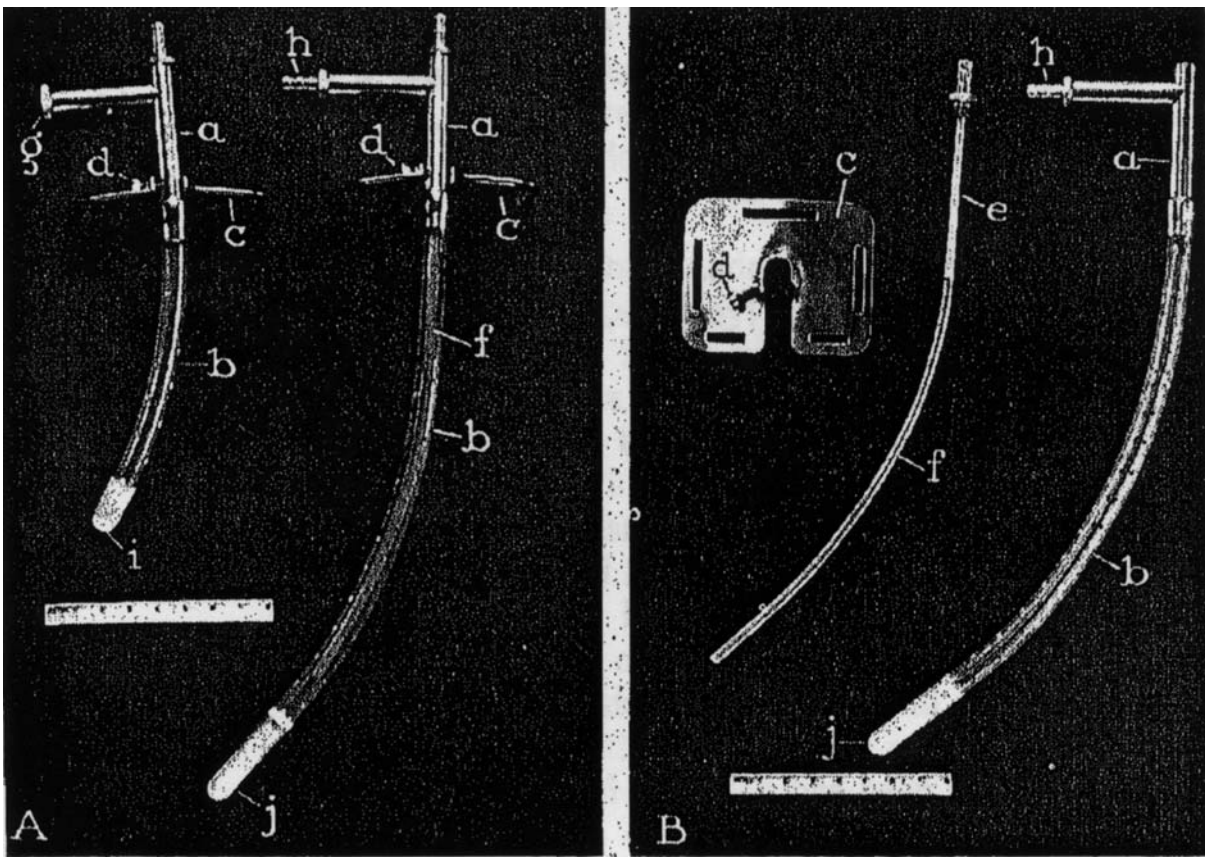

Fig. 14.5 Ferris and Odel tubes for peritoneal lavage. The assembled tubes are on the left. The short tube on the left is the inflow tube. The outflow tube on the right is disassembled to show the component parts. A = rigid extra-abdominal, b = polyvinyl intra-abdominal outer tube, c = malleable metal flange, d = thumbscrew, e = rigid inner portion, f = polyvinyl inner portion, g = metal plug, h = adapter, i = inflow bendaloy, j = outflow bendaloy. Modified from [20]

coil they used a polyvinyl tube with multiple perforations. This tubing was "sweated" into the stainless steel portion of the tube with acetone. The tips of the tubes were provided with plugs consisting of bendaloy[6] completely encased in the polyvinyl. The tubes were weighted with these plugs to insure they would hang dependently in the peritoneal cavity. This was particularly important for the outflow tube to keep the tip in the true pelvis, the place of a fluid reservoir. The intra-abdominal portion of the inner tube was also made of polyvinyl. The extra-abdominal part of the catheters remained essentially unchanged, with the exception of the plate (flange). They cut a slot in the flange so that it could be slipped on the tube after implantation, when proper position of the flange could be determined. Ferris and Odel introduced two important ideas in their access: 1) use of plastic (polyvinyl) for the intra-abdominal segment of the access, and 2) use of weights to keep the tip of the tubing in the true pelvis. Both ideas were emulated later by other inventors.

In 1948, Frank et al. reported further experience with peritoneal irrigation based on 14 additional patients in renal failure [21]. The peritoneal access was markedly modified (Fig. 14.6). Only a sump drain was used for inflow and outflow. The external part of the drain was made of glass closed with a rubber stopper, and contained a side arm for fluid inflow and air inlet. This glass portion was connected through an external flexible rubber tube to a stainless steel tip. An internal flexible rubber tube of a smaller diameter than the external was inserted through the rubber stopper up to the stainless steel tip and connected to the suction line. For the insertion of the sump drain, two incisions were made. The upper incision through the skin to the fascia was made beneath the costal margin; the lower incision entering the peritoneum was made in the lower abdomen on the opposite side. A subcutaneous tunnel connecting these two incisions was made; the metal end of the flexible sump drain was inserted through the upper incision, passed along the tunnel, and inserted into the peritoneal cavity through the lower incision. Thus, for the first time, a long subcutaneous tunnel was created for the peritoneal access. "The patient lies semi-erect so the fluid in the pelvis remains below the upper incision. Thus no contact by possible ebb flow can be made between the fluid and the skin of the abdominal wall." The authors used intermittent or continuous flow technique. For continuous flow technique they used "a small rubber inflow catheter" and a sump drain for outflow. The intermittent flow technique was accomplished with a new catheter by alternating inflow and suction (Fig. 14.7). In intermittent flow peritoneal dialysis, various volumes (500–2,000 mL) were introduced as determined by patients' tolerance, allowed to remain for 15 min to 3 h, after which the fluid was aspirated. Any air entering the system was bubbled through an alkaline solution of parachlorophenol and cresol. Peritonitis episodes were frequent, but edema was not a problem in most patients because hypertonic solutions were used. They cautioned against using too concentrated solutions. In one patient, "a solution of 5% gelatin and 2.5% glucose withdrew fluid so rapidly as to produce shock. Moreover, the hypertonicity may be responsible for the peritoneal irritation and by increasing it still further infection may be even more likely" [21].

A major advance was the introduction of less rigid materials by French physicians in 1949 [22]. They designed polyvinyl tubes, 25–30 cm long, with diameters of 2–3 mm. The terminal 15 cm of the tubes had lateral openings, all 2 or 3 mm. The tubes were introduced into the abdominal wall with the help of trocars. After local anesthesia, the trocar with pointed mandrel was introduced into the peritoneal cavity, then the pointed mandrel was replaced with a blunt rod and the trocar was advanced deeper without the risk of peritoneal trauma. Finally, the rod was removed and the polyvinyl tube was introduced through the trocar sheath. After infusion of 3–4 L of solution, the outflow tube was inserted on the opposite side of the abdomen with the same technique. The authors were very satisfied with the performance of the polyvinyl tubes.

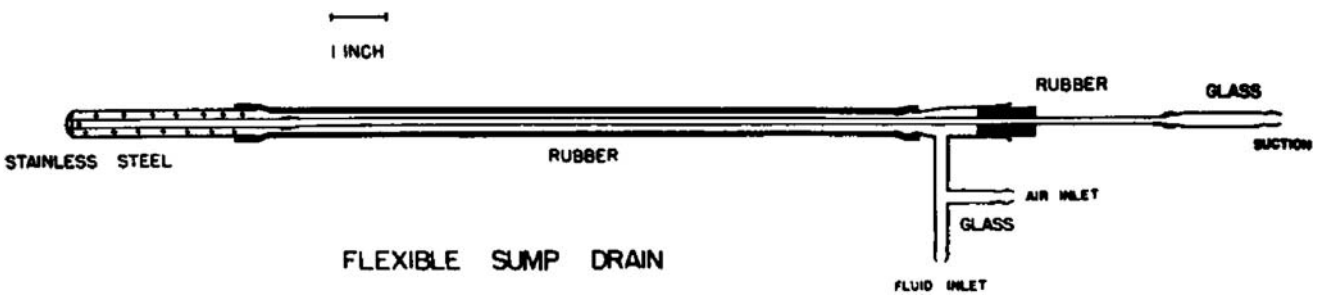

Fig. 14.6 Flexible sump drain of Frank, Seligman, and Fine. Modified from [21]

[6] Titanium-molybdenum alloy

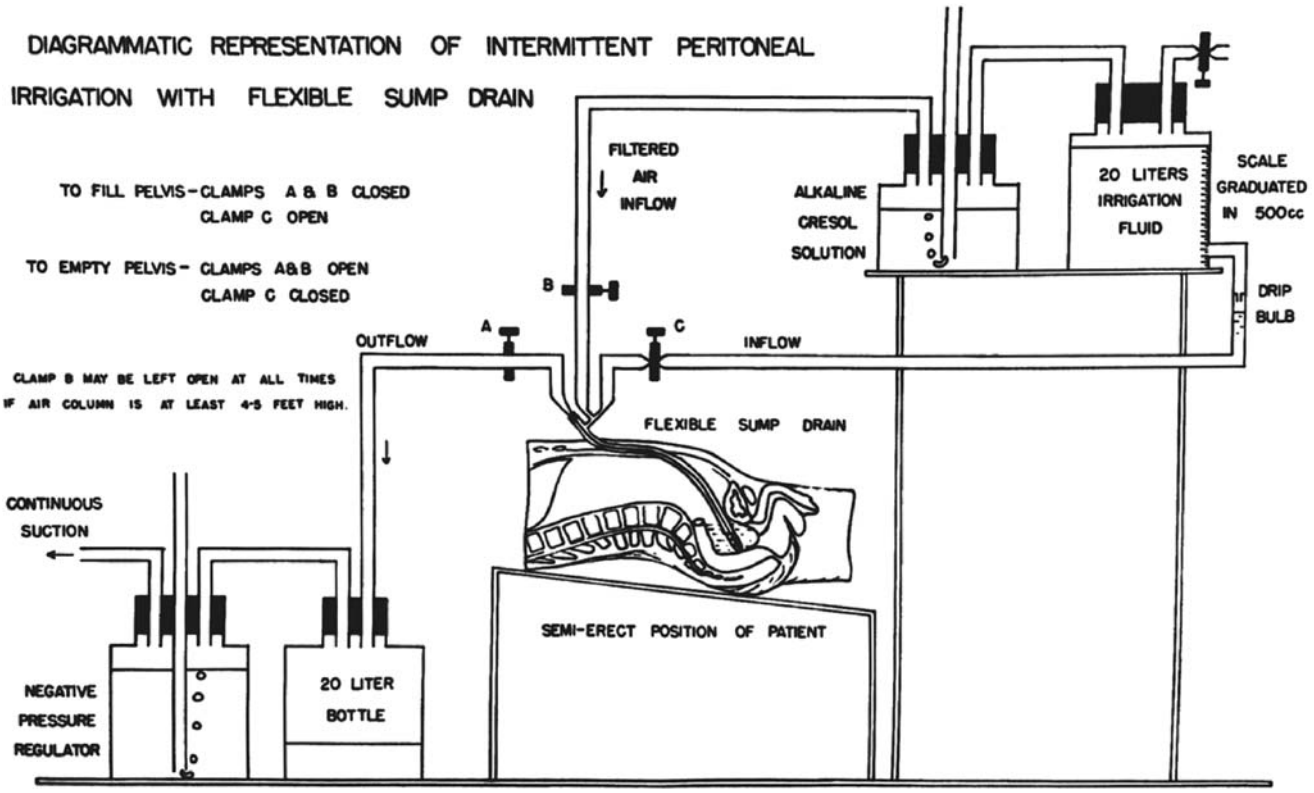

Fig. 14.7 Diagrammatic representation of intermittent peritoneal irrigation with flexible sump drain. Note: to fill pelvis – clamps A & B closed, clamp C open; to empty pelvis – clamps A & B opened, clamp C closed; clamp B might be left open at all times if air column was at least 4–5 feet high. Modified from [21]

Rapid progress in peritoneal dialysis was made in the 1950 s. Grollman et al. [23, 24] reported their experience with intermittent[7] peritoneal lavage in nephrectomized dogs and in five patients. In dog experiments, 1 L of peritoneal fluid was infused into the peritoneal cavity through a needle. After a variable dwell time the fluid was siphoned off through the same size needle, followed by refilling. The exchanges were usually done twice daily in the morning and late afternoon. The technique was modified for patients. The fluid was infused into and drained from the peritoneal cavity through a single polyethylene tube placed through the anterior abdominal wall. "A trocar was inserted as in the routine removal of ascites fluid, the stylet replaced with the polyethylene plastic tube, and the trocar[8] removed." The lavage lasted between 16 and 48 h. According to their experience, "The intermittent procedure just described avoids the complex apparatus, multiple incisions and constant attention necessary when one utilizes a constant perfusion technique. It is, nevertheless, almost equally effective as a means of replacing renal excretory function since ... it requires several hours for equilibrium to be established between fluid in the peritoneum and the blood. A continuous lavage tends, moreover, to result in the channeling of the perfusion fluid and hence may actually prove less efficient..." [23].

The next major progress was made in the late 1950 s when Maxwell et al. reported their experience with 76 peritoneal dialyses [25]. Seemingly minor improvements in the technique provided major improvements in results. The catheter was introduced with a technique similar to that of Grollman et al. [23], but the semirigid catheter was made of nylon[9]

[7] There has been some confusion regarding the terms *intermittent* and *continuous* peritoneal dialysis. Some authors applied the term *continuous* if the lavage was carried on for several days without interruption, and the term *intermittent* if the lavage was interrupted for a night or a day or two [21]. Others applied the term *continuous* if peritoneal fluid flowed continuously between the inflow and outflow accesses. In this terminology, intermittent lavage was carried with only one access and the flow was interrupted [2]. Grollman and his colleagues used the term *intermittent* in the latter meaning, but they performed continuous lavage in the other understanding of this word. To avoid confusion, there was a proposal to use the term *continuous peritoneal dialysis regimen* for dialysis carried out day and night 7 days per week without interruption and *continuous flow peritoneal dialysis technique* for the other meaning of this word.

[8] Here, by trocar, the authors understood the sheath or cannula of the trocar,

[9] Nylon is made of repeating units with amide linkages between them. Hence, it is frequently referred to as a polyamide. Various forms of nylon with various properties are available.

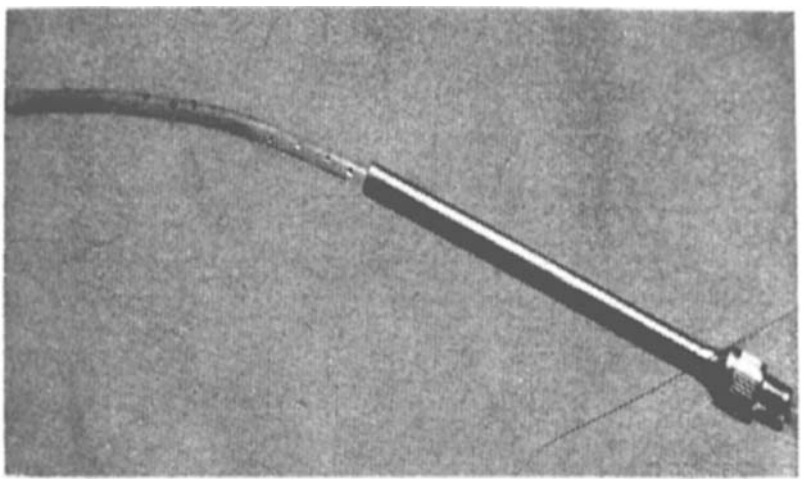

Fig. 14.8 Maxwell's trocar and permanently curved nylon (polyamide) catheter with rounded tip and multiple small perforations at the distal end. Reprinted with permission from [25]. Copyright © 1959, *American Medical Association*. All rights reserved

instead of polyethylene, had rounded tip, and had numerous very tiny perforations (80 holes of 0.02 inch[10] diameter) instead of larger openings at the distal 3 inches (Fig. 14.8). The authors believed that the use of nonirritating plastic prevented omentum and intestines from clinging to the catheter, and that the small diameter of perforations prevented particles of omental fat from plugging the catheter. They used a 17F Duke trocar set for insertion of the catheter.

At the same time, Doolan and co-workers [26] developed a polyvinyl catheter with multiple ridges to prevent omental wrapping. Both catheters were inserted into the peritoneal cavity with the help of a paracentesis trocar. Smooth, plastic materials were much less irritating to the peritoneum than previously used glass, rubber, or steel, thereby omental occlusion became less frequent. The drainage of fluid from the peritoneal cavity was markedly improved, but leakage and pericatheter infections continued to plague the access.

In the early 1960 s, various conduits, buttons, and prostheses were developed to facilitate repeated entrance to the peritoneal cavity. These devices never gained popularity as major complications, particularly peritonitis and adhesion formation leading to technical difficulties, were not eliminated [4]. Disappointed with these poor results, Boen and his collaborators developed the repeated puncture method and published their experience in 1964 [27]. The semirigid catheter was inserted through the 14F trocar described by McDonald [28]. The catheter was removed after each dialysis. Intermittent peritoneal dialysis was carried out once weekly for 14–24 h with 3 L of fluid per hour with the use of cycling machine.

Although McDonald's thin-walled 14F trocar significantly decreased the incidence of pericatheter leaks and bleeding, common with previously used 17F trocars, these were not eliminated. To circumvent these problems, Weston and Roberts invented a stylet catheter, which was inserted without a trocar [29]. A sharp stainless steel stylet ("three-sided trocar point") inserted through the nylon catheter was used to penetrate the abdominal wall (Fig. 14.9). As a result, the abdominal opening fitted snugly around the catheter, thereby preventing leakage. Only local anesthesia was used for catheter insertion. Before catheter insertion the abdomen was filled with dialysis solution via a 14 or 15 gauge needle inserted through the *linea alba* below the umbilicus. Then a small incision was made in the skin, the catheter with the stylet was pierced through the abdominal wall, then the stylet was withdrawn, the catheter advanced to the right or left pelvic gutter, and dialysis was started with 2 L exchanges. After dialysis the catheter was usually removed. This type of catheter is still being used for acute renal failure.

A major step forward in creating a permanent peritoneal access was made in 1964. Gutch [30] noticed lower protein losses with silicon rubber catheters as compared to those with polyvinyl ones, which suggested less irritation of the peritoneum with a new material. About the same time, Palmer, with the help of Wayne Quinton, already successful in manufacturing silicon rubber shunts for hemodialysis, developed a catheter which is a prototype of currently used coiled catheters [31]. The catheter was made of silicon rubber, the intraperitoneal end was coiled and had numerous perforations extending 23 cm from the tip, a long subcutaneous tunnel was supposed to hinder periluminal infection (Fig. 14.10). To impede further infection and leakage, a tri-flanged step was created for securing the catheter in the deep abdominal fascia.

In 1965, Henry Tenckhoff, at the University of Washington, was beginning to treat patients on chronic peritoneal dialysis [32]. After initial few dialysis in the hospital, the patients would be trained for home dialysis. On the weekends,

[10] 0.02 inch = 0.0508 mm

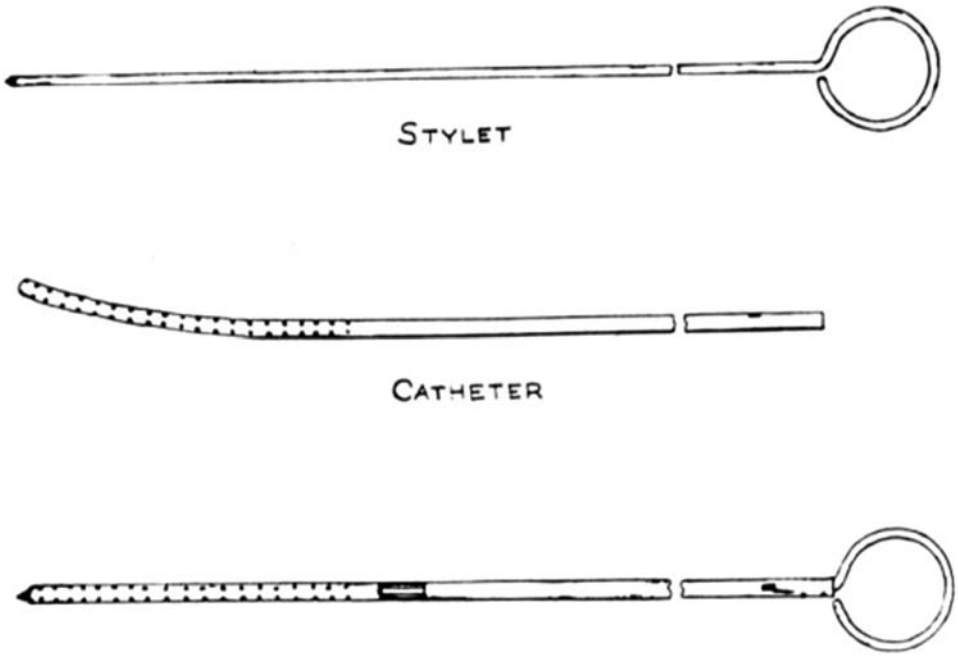

Fig. 14.9 Weston and Roberts' stylet catheter. Modified from [29]

Tenckhoff would go to patient's home, insert the catheter, and begin dialysis. After the appropriate time on dialysis, the patient would remove the catheter and cover the exit wound with a dressing. Although the method was successful in Tenckhoff's hands, the technique was cumbersome, and Tenckhoff recognized its limitations.

In 1968, McDonald and co-workers [33] developed an external seal composed of polyester (Dacron®) sleeve and polytetrafluoroethylene (Teflon®) skirt. Tissue ingrowth into these elements created a firm external seal to prevent leakage and microorganism migration. No subcutaneous tunnel was created; the catheter was inserted straight through the abdominal wall. This catheter never gained popularity, as at the same time Tenckhoff and Schechter published the results of their studies on a new catheter, which provided results superior to any other catheter designed so far [34]. Their catheter (Fig. 14.11) was an improved version of the Palmer catheter. An intra-abdominal flange was replaced by a Dacron® cuff, a subcutaneous tunnel was shortened, and the second, external cuff was used to decrease the length of the catheter sinus tract. Ultimately, the coiled intraperitoneal portion was replaced by a straight segment resembling the Gutch catheter. Intraperitoneal segment was kept open ended and the size of the side holes was optimized to 0.5 mm to prevent tissue suction. A shorter subcutaneous tunnel and straight intraperitoneal segment facilitated catheter implantation at the bedside with the aid of a specially designed trocar (Fig. 14.12). To avoid excessive bleeding the catheter was inserted through the midline. The Tenckhoff catheter has become the gold standard of peritoneal access. Even today, 40 years later, the Tenckhoff catheter in its original form is the most widely used catheter type. Some of the original recommendations for catheter insertion, such as an arcuate subcutaneous tunnel with downward directions of both intraperitoneal and external exits, are still considered very important elements of catheter implantation.

The most common complications of the Tenckhoff catheter included exit/tunnel infection, external cuff extrusion, obstruction (which was usually a sequel of catheter tip migration out of the true pelvis with subsequent omental wrapping or tip entrapment in peritoneal adhesions), dialysate leaks, recurrent peritonitis, and infusion or pressure pain. Numerous devices were tried to improve the results achieved with Tenckhoff catheter – most of them unsuccessfully as this catheter is still preferred by most nephrologists for treatment with peritoneal dialysis.

To prevent exit infection, a subcutaneous catheter was developed by the Stephen et al. [35]. The catheter had two tubes in the peritoneal cavity, and a subcutaneous container. The container was to be punctured for each dialysis. This device was used for continuous flow peritoneal dialysis. To decrease peritonitis episodes, Gotloib et al. [36] developed a prosthesis, which consisted of a Teflon® tube with internal diameter similar to the external diameter of the peritoneal catheter. The head of the tube was funnel shaped to simplify insertion of the catheter. The prosthesis was implanted surgically with the head located in the subcutaneous tissue and the tube penetrating through the parietal peritoneum. After a week, dialysis was started. The skin over the prosthesis head was pierced with a stylet and then the catheter

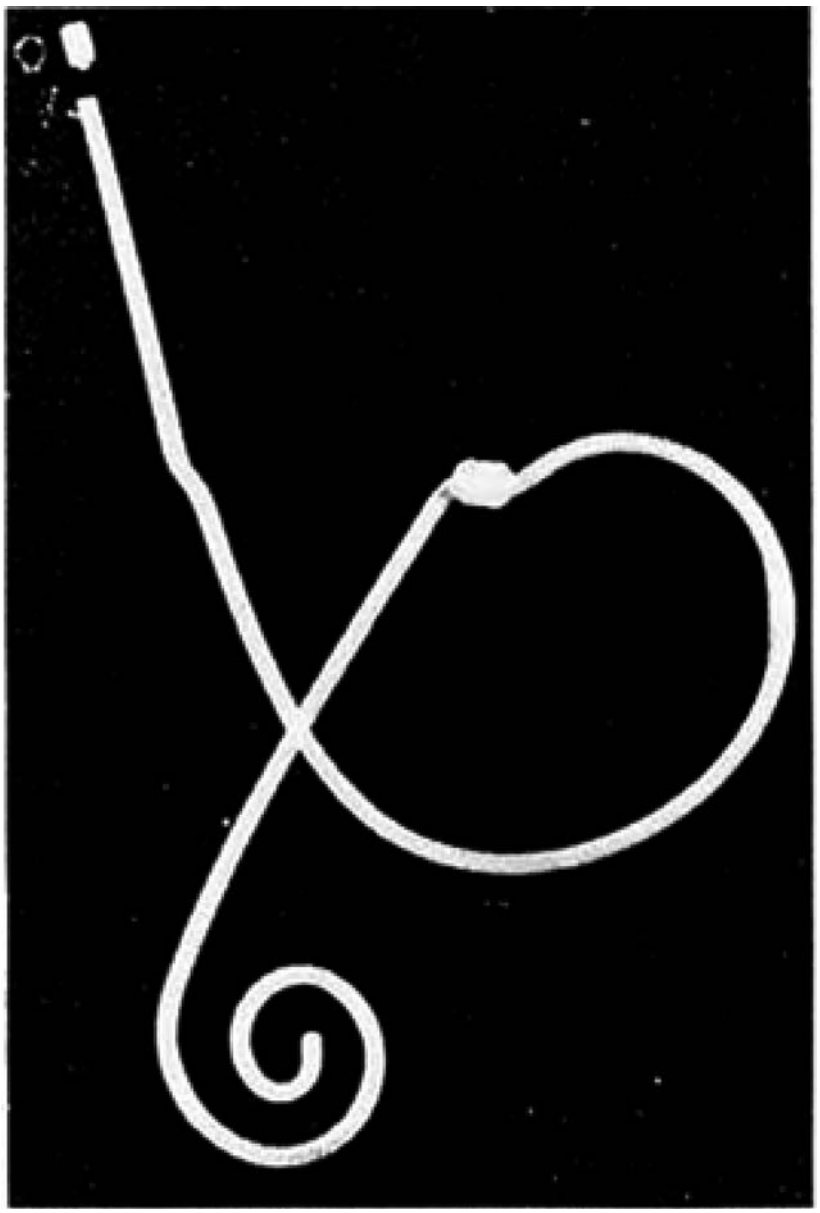

Fig. 14.10 Palmer and Quinton's silicone rubber catheter with triflange step (A) and coiled tip (B). Modified from Palmer, Quinton, and Gray [31]

introduced into the prosthesis, the stylet removed, and the catheter advanced to the pelvic gutter. The catheter was removed after each dialysis. Yet another approach to decrease exit-site infection rates was to position the subcutaneous cuff at the skin level [37]. The catheter tubing was made of Silastic to which was attached a transcutaneous segment with a flange and cuff of expanded polytetrafluoroethylene (PTFE). The flange was located subdermally and the collar protruded through the skin. The cuff was placed perpendicularly through the subcutaneous tissue without a lateral tunnel. Unfortunately, contrary to expectations, such a position tends to increase infection rates [38].

To decrease catheter migration and omental wrapping the intraperitoneal segment of the catheter was provided with a saline inflatable balloon [39] or discs [40]. Valli et al. [41] revived an idea of bulbous distension of glass cannula [7, 9], but, instead of glass, a stiffened silicone rubber with a balloon surrounding the catheter tip was used. In an improved version, the preballoon segment of the intraperitoneal portion of the catheter was eliminated and the balloon was attached to the abdominal wall to avoid migration. The internal segment in the balloon was eliminated; the tube ended at the balloon, which was smaller than in the previous version. Thus, the improved catheter (Valli-2) in its concept was very close to those of mushroom or column disc catheters, but with better material and smaller and more numerous holes [42]. This balloon cannot migrate but still may be obstructed by bowel or omentum. Thornhill et al.

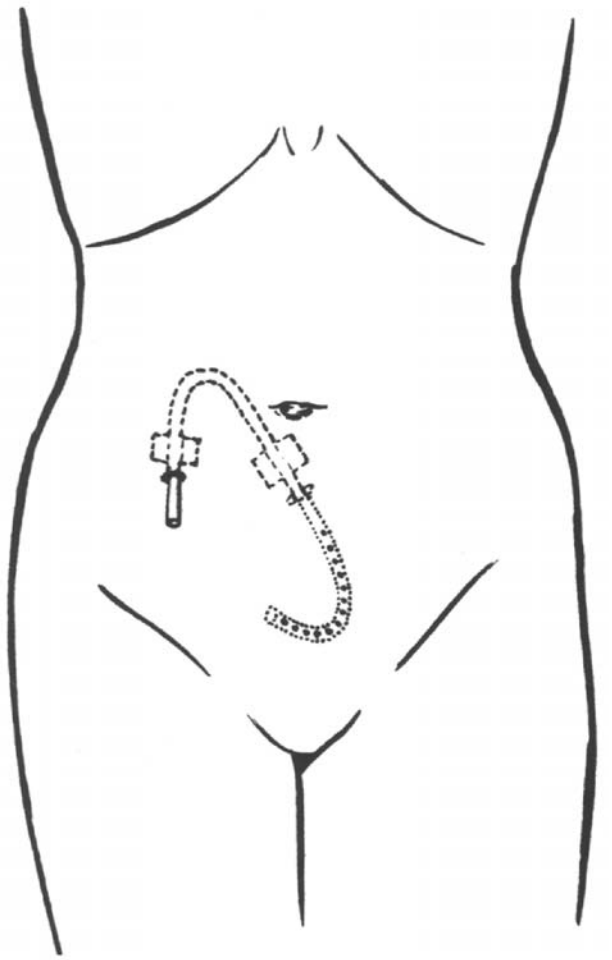

Fig. 14.11 Properly implanted Tenckhoff and Schechter silicone rubber catheter with two cuffs. Modified from [34]

[43] returned to the concept of implanting a mushroom-like structure just below the peritoneum in the left lower abdominal quadrant. However, unlike the de Pezzer rubber catheter, the head of their catheter was made of two parallel discs of silicone elastomer separated by short pillars and anchored to the abdominal wall by a Dacron® felt sleeve. They believed that the column disc catheter would perform better than the mushroom catheter used in the 1940 s and even better than the Tenckhoff catheter. Unfortunately, this was not the case. Compared to the Tenckhoff catheter the rate of catheter obstruction was higher and the catheter survival was markedly lower in the subsequent clinical study [44]. The use of this catheter gradually ceased. In 1993, Ash and Janle [45] changed the intraperitoneal segment of the catheter from the column disc to a longitudinal tube with 1-mm wide "flutes" or grooves on the surface. The intraperitoneal segment lay against the parietal peritoneum and was connected perpendicularly to a transabdominal tube, thus creating a "T"-shaped catheter. The catheter cannot migrate, but still may be obstructed by bowels, adhesions, or omentum. Another approach was undertaken by Chiaramonte et al. [46, 47]. Because the best position of the catheter tip for dialysate outflow is in the true pelvis, they decided to shorten the catheter and implant it very low, just a few centimeters above the symphysis pubis. Such a catheter had a limited capability to migrate outside of the true pelvis and the omental wrapping was less likely as in the majority of people the omentum does not reach below the pelvic brim. This was a return to the old idea of locating an outflow peritoneal access very low, in the Douglas cavity, where conditions for fluid drainage were the best. The insertion point was either on the *linea alba* or McBurney point, 3–4 cm over the pubis. According to the authors, the catheter obstruction rate was very low, other complications were not worse than with the Tenckhoff catheter, with the exception of pericatheter leaks, which were significantly higher. This was related to the low insertion site of the catheter, near the pubis, where intraabdominal pressure in the upright position is higher compared to that of the insertion site of the Tenckhoff catheter near the navel. To keep the catheter tip in the true pelvis, Di Paolo et al. [48] returned to the idea of Ferris and Odel [20] of adding weights into the catheter tips. Instead of bendaloy they incorporated a 12-g tungsten weight at the silicone rubber catheter tip.

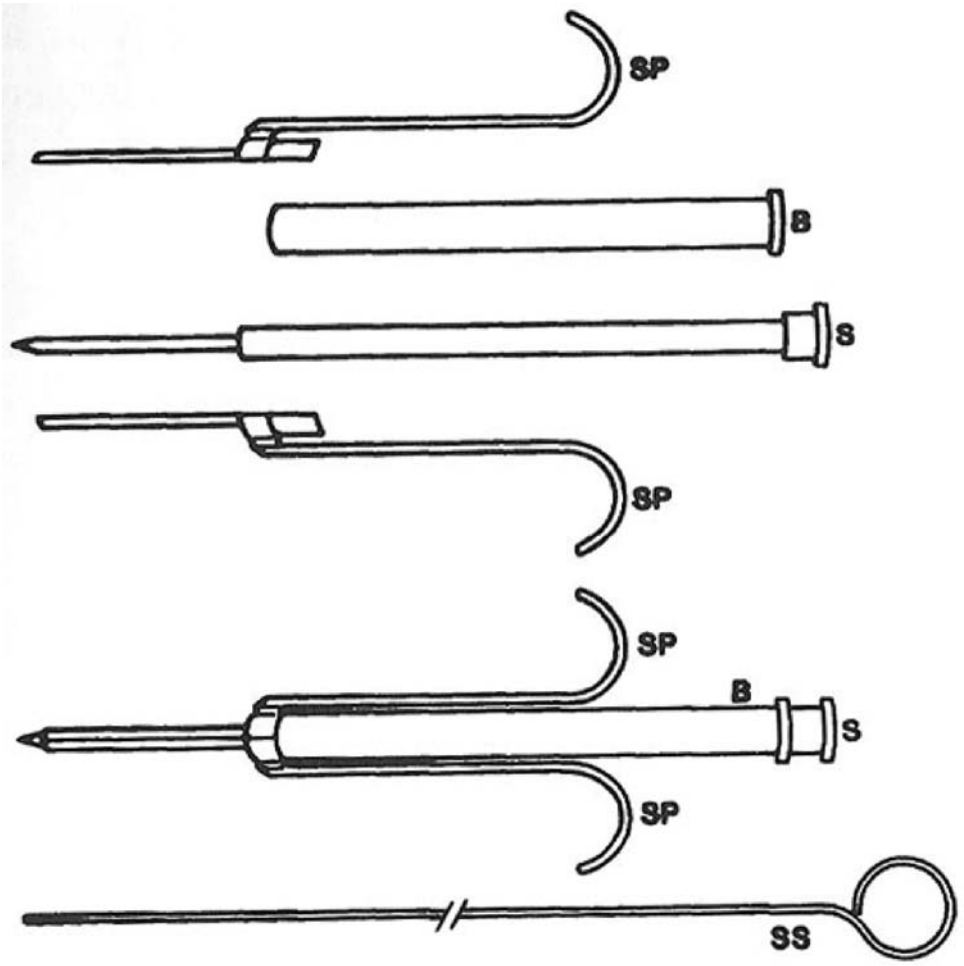

Fig. 14.12 Tenckhoff trocar – assembled (above) and disassembled (below). SP – side pieces; S – pointed stylet; B – barrel; SS – stiffening stilette

Early peritoneal accesses were plagued by pericatheter leaks. The Tenckhoff catheter with Dacron® cuffs drastically decreased this complication in supine peritoneal dialysis. The introduction of ambulatory peritoneal dialysis once again increased the frequency of pericatheter leaks because of increased intraabdominal pressure in the upright position. To prevent this complication, a new catheter was designed. The catheter, dubbed the Toronto Western Hospital Type 2 (TWH-2), was made of silicone rubber tubing and was provided with two cuffs, similar to the Tenckhoff catheter, and two silicone rubber discs to curtail catheter migration; however, it had new features. The catheter was provided with a polyester disc (flange) at the base of the deep cuff and a silicone rubber ring (or bead) situated close to the flange that provided a groove in which a purse string suture could tie the peritoneum tightly [49]. These innovations by themselves did not decrease leakages, so the authors signaled that they started a modified implantation technique. Instead of implantation through the *linea alba*, the catheter was inserted though the rectus muscle.

Several catheters have been developed in recent years aimed at eliminating or decreasing multiple complications of Tenckhoff catheters. Twardowski et al. [50] designed silicone rubber "swan-neck" catheters that are permanently bent between two cuffs. These catheters may be implanted in an arcuate tunnel with their shape undistorted. A similar principle was applied by Cruz to polyurethane catheters (Fig. 14.13) [51]. In 1992, Twardowski et al. [3, 52] described a new catheter that had an exit site on the chest instead of the abdomen (Fig. 14.14). Moncrief et al. [53] described a modified swan-neck catheter with an elongated external cuff. They also substantially changed technique of catheter insertion by keeping the external part under the skin until the ingrowth of the tissue into the cuff is strong. Only after several weeks (three to six or more) is the external part exteriorized.

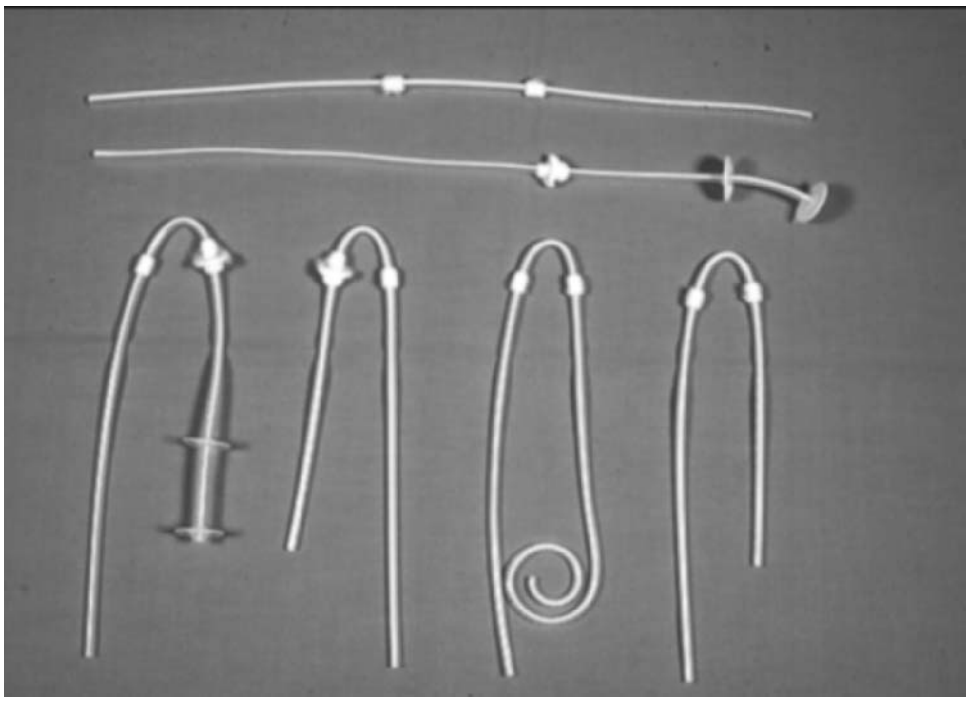

Fig. 14.13 Tenckhoff, Toronto Western Hospital (TWH) catheters and various swan-neck catheters. All swan-neck catheters have two cuffs and bent intramural segment. Swan-neck Missouri catheters have a slanted flange and bead at the deep cuff

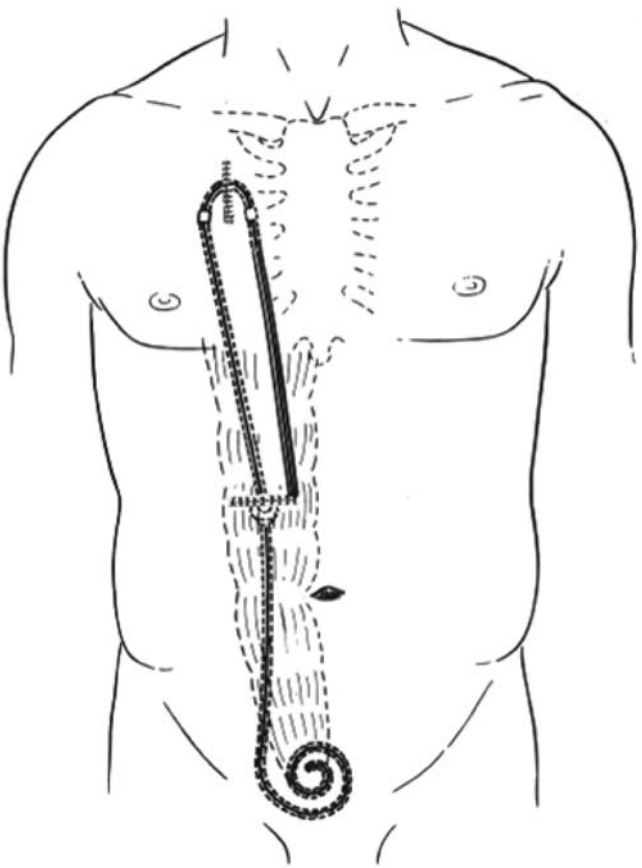

Fig. 14.14 Swan-neck presternal catheter after implantation. The deep cuff with flange and bead is shown in the rectus muscle; the titanium connector is 2–3 inches (5–7.5 cm) above the deep cuff. The middle and superficial cuffs are in the parasternal area, and the exit is 3 cm below the external cuff. Modified from [52]

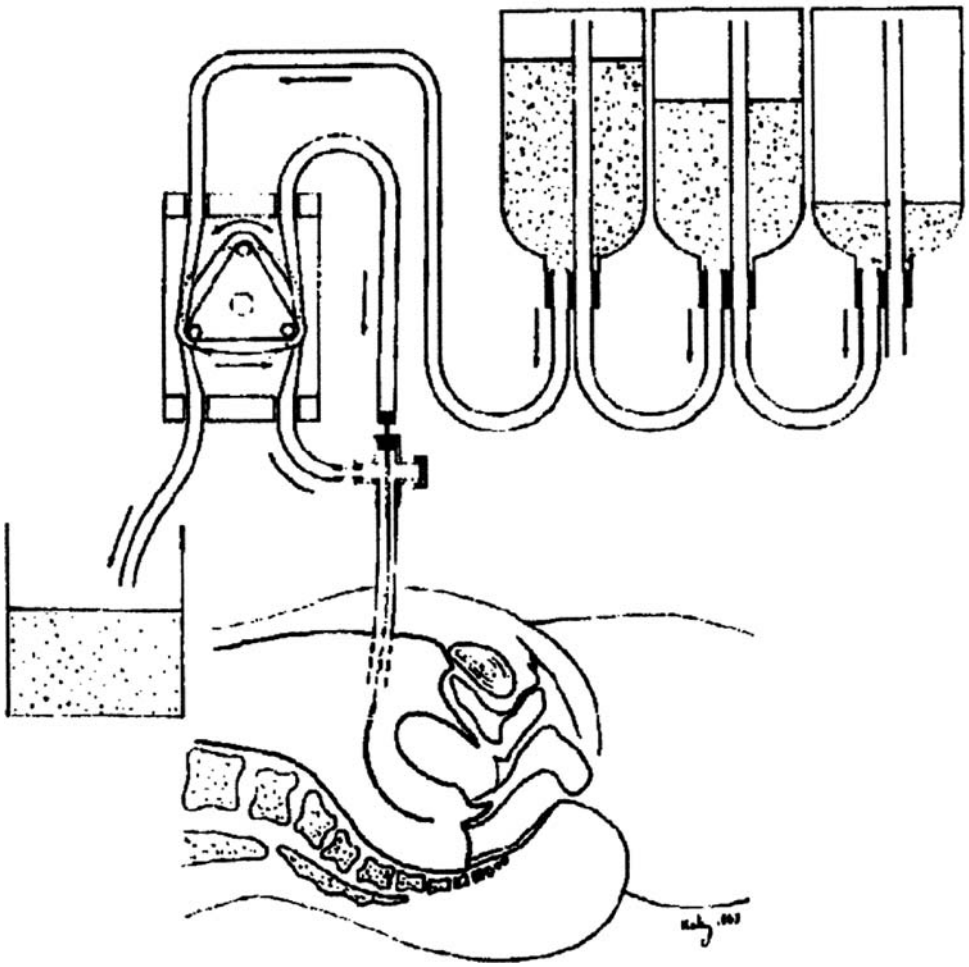

Fig. 14.15 Automatic continuous flow peritoneal dialysis of Lange, Treser, and Mangalat. A = inflow. B = outflow. Modified from [55]

Continuous flow peritoneal dialysis, introduced in animals in 1926 by Rosenak and Siwon [7] and in humans by Balázs and Rosenak in 1934 [9], was used concomitantly with intermittent flow peritoneal dialysis until the late 1960 s (Fig. 14.15). High fluid flows were used with either two catheters [22, 54] or double-lumen catheters. One double-lumen catheter was developed by Lange et al. [55]. The catheter (Fig. 14.16) was composed of a short nylon catheter of 15 cm length with an outer diameter of 4.7 mm and inner diameter of 4 mm and numerous perforations in the distal 3 cm. The catheter was introduced into the peritoneal cavity with a trocar under local anesthesia; the trocar was removed and the catheter was attached to a four-way connector and 2,000 mL of solution was infused to the peritoneal cavity. Immediately thereafter, a stiff nylon catheter, 37 cm long, with an outer diameter of 2.2 mm and inner diameter of 1.4 mm was introduced to the pelvic gutter through the lumen of the large catheter. The internal catheter was tightly sealed in the opening of the cross and connected to the inflow tubing. The fluid inflow was through the inner catheter to the pelvic gutter and drainage was through the large catheter with openings below the parietal peritoneum of the anterior abdominal wall. Stephen et al. [35] used their subcutaneous catheter for recirculating peritoneal dialysis, which was an offshoot of continuous flow peritoneal dialysis.

The technique of continuous flow peritoneal dialysis was abandoned after the advent of continuous ambulatory peritoneal dialysis regimen in the late 1970 s as it was associated with technical difficulties due to catheter obstruction, abdominal pain related to high flow, and less then expected dialysis efficiency because of fluid channeling [56]. There is a renewed interest in continuous flow peritoneal dialysis, as it is believed that new peritoneal accesses may make this modality successful. One of these catheters, a fluted double-lumen catheter, has been recently described by Diaz-Buxo from Fresenius Medical Care North America, Lexington, Maryland, USA [57, 58]. Within the abdominal wall, this catheter consists of two tubes using a novel configuration, where one slightly oval-shaped tube embeds within the other crescent-shaped tube. Externally, the tubes are separate. Intraperitoneally, the tubes are also separated, with each tube terminating with a fluted section. The internal part of this double-lumen catheter is similar to the T-fluted catheter with

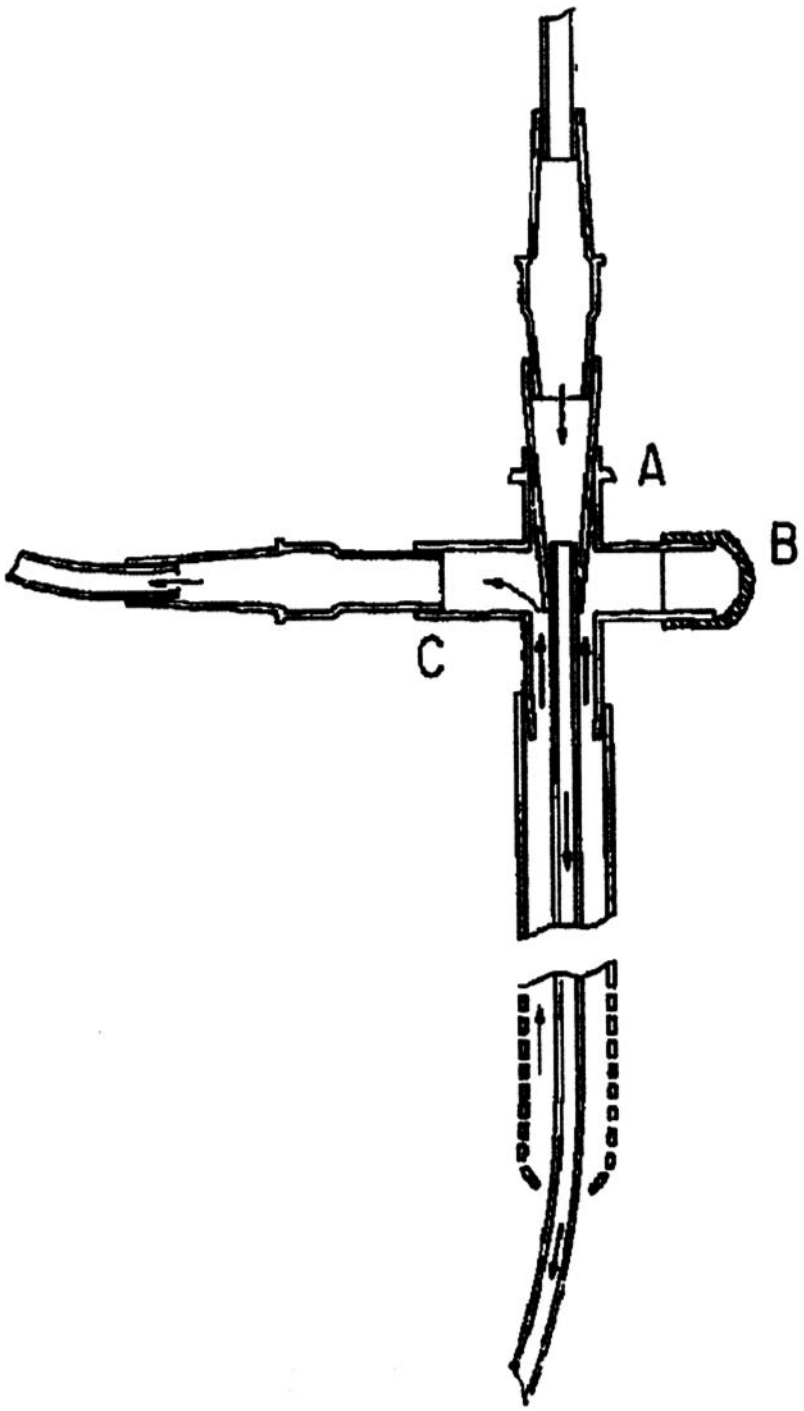

Fig. 14.16 Lange, Treser, and Mangalat's double-lumen catheter for continuous flow peritoneal dialysis. Modified from [55]

the exception that the latter is a single-lumen catheter. Another catheter, a double-lumen catheter with diffuser, has been recently developed by Ronco et al. [59]. The intraperitoneal segment of the outflow tubing has a coiled design. The intraperitoneal segment of the inflow tubing is a short, thin-walled, silicone rubber, round, tapered diffuser with multiple side holes, which allow the inflowing dialysis solution to be dispersed just below the parietal peritoneum, far away from the outflow tubing tip. This design is a reversal of the catheter of Lange et al. [55], where inflow was to the pelvic gutter and drainage through the large catheter with openings below the parietal peritoneum of the anterior abdominal wall.

In agreement with the general pattern of biological and technological evolution, the first peritoneal accesses were devices that had been used in other fields of medicine or surgery. Gradually, the accesses were designed specifically for

peritoneal dialysis. Most of the designs improved the performance of peritoneal accesses, although some led nowhere and were abandoned. The major breakthrough came in the 1960 s with the invention of the Tenckhoff catheter.

Technological evolution never ends. Multiple attempts are being made to eliminate remaining complications of the Tenckhoff catheter, such as exit/tunnel infection, external cuff extrusion, migration leading to obstruction, dialysate leaks, recurrent peritonitis, and infusion or pressure pain. New designs combine the best features of the previous catheters or incorporate a new element. Not all attempts are successful, but many are. The swan-neck catheters with the permanent bend of the silicone rubber in the intratunnel segment have been among the most successful. Consecutive gradual improvement leading to the classic Tenckhoff catheter and subsequent modification of the Tenckhoff catheter are summarized in Table 14.1.

Other innovations have included surface modification of catheters to reduce infections. Silver, because of its antimicrobial activity, has been studied extensively. Surface coating of catheters using ion-beam-assisted deposition

Table 14.1 Development of new features in peritoneal accesses for dialysis in humans

1st Author	Year	Ref.	Fig.	Main new feature(s)	Prior similar concept(s) [ref.]
Balázs	1934	[9]		Bulbous distention of the tip	Sprinkling can rose-like tip of glass cannula (Rosenak and Siwon [7])
Seligman	1946	[13]		Rubber catheter inserted through a trocar	Rubber catheters used in surgery, urology, and gynecology
Rosenak	1948	[18]	2	Sump drain with flexible (spiral spring wire) intra-abdominal part	Sump drain used in surgery
Ferris	1948	[20]	3	Polyvinyl intra-abdominal part; weight to keep the tip in true pelvis	Modification of Rosenak and Oppenheimer [18]
Frank	1948	[21]	4, 5	Flexible rubber tube in a long subcutaneous tunnel	Long tunnel was a new concept for a modified sump drain
Dérot	1949	[22]		Polyvinyl catheter inserted through a trocar	Trocar (Seligman et al. [13]); polyvinyl tube (Ferris and Odel [20])
Grollman	1951	[23]		Polyethylene tube inserted through a trocar	Polyethylene for a catheter is a new concept
Maxwell	1959	[25]	6	Polyamide catheter inserted through a trocar; very tiny lateral perforations, closed tip	Polyamide for a catheter and very tiny perforations were new ideas. Sump drains had a closed tip
Weston	1965	[29]	7	Pointed stylet inside polyamide catheter	Modification of Maxwell et al. [25] catheter
Gutch	1964	[30]		Silicone rubber for catheter tube	Silicone rubber used for hemodialysis shunts and abdominal surgery
Palmer	1964	[31]	8	Silicone rubber, long tunnel, triflange step, coiled tip	Silicone rubber (see above) long tunnel (Frank et al. [21]). Triflange step and coiled tip were new concepts
Tenckhoff	1968	[34]	9, 10	Polyester cuffs attached to silicone rubber catheter	Silicone rubber (Palmer et al. [31], Gutch [30]), cuff was a new concept for peritoneal dialysis catheter
Oreopoulos	1976	[40]	12	Intraperitoneal silicone discs	Protection from omental wrap and tip translocation by distensible balloon (Goldberg and Hill [39])
Ponce	1982	[49]	12	Flange and bead at deep cuff. Insertion through the rectus muscle	These were new concepts
Valli	1983, 1988	[41, 42]	12	Silicone balloon tip with multiple perforations	Bulbous distension of glass cannula (Rosenak and Siwon [7], Balázs and Rosenak [9])
Chiaramonte	1985, 1992	[46, 47]	12	Short intraperitoneal segment, catheter implanted close to the symphysis pubis	Modified Tenckhoff catheter. Implantation of catheter just above the Poupart's ligament (Weiss and Mills [16])
Twardowski	1985	[50]	12	Permanent bend of intercuff segment	Permanent bend was a new idea
Twardowski	1992	[3]	12	Exit on the chest, long tunnel, three cuffs	Exit on the chest and three cuffs were new ideas. Frank et al. [21] and Palmer et al. [31] designed long tunnels
Di Paolo	1996	[48]	12	Tungsten weight at the catheter tip	Bendaloy weight at the tip (Ferris and Odel [20])

of silver was shown to be effective in reducing infections in our initial animal studies [60, 61], but such catheters have not been studied in human subjects. Another technology to treat catheters is by silver ion beam implantation therapy, wherein the silver ions penetrate the catheter to a depth of 200–300 nm. In a study of 67 such silver-treated catheters and 72 controls, no differences in exit-site infections or peritonitis were noted [62]. The failure to reduce infections may be secondary to the low surface availability of silver. Further, the lack of effect on peritonitis may be secondary to the lack of silver in the internal lumina by this technology. An alternative is to impregnate the catheter matrix with silver. The distribution of submicron silver evenly through the matrix creates a larger antimicrobially active surface than can be created by surface coating [63]. The silver ions are released from the matrix into the unstirred water layer of the surface and are available to interact with the free sulfhydryl groups of bacterial enzyme systems [63]. In vitro studies have demonstrated the antimicrobial activity of these silver-impregnated catheters against coagulase-negative staphylococci (CNS), *Staphylococcus aureus, Enterococcus faecalis, Escherichia coli, Pseudomonas aeruginosa,* and *Candida albicans* [64]. While no studies have been done with silver-impregnated peritoneal dialysis catheters, clinical tests with silver-impregnated vascular catheters have not consistently shown favorable results [65, 66].

A preliminary evaluation of a silver ring device mounted on a catheter showed significant reductions in exit-site infections in a population with a very high exit-site infection rate [67]. A subsequent randomized study showed this device to be ineffective in reducing catheter-related infections. The rate of catheter explantation was similar in the study and control group. Displacement of the silver ring into the tunnel track contributed to infections and catheter loss in almost 6% of the patients [68]. The authors postulated that the piston movement of the catheter may have prevented the ring from being in constant contact with the skin.

Early exit site colonization is associated with higher catheter loss [69]. This has led to studies with antibiotic coated catheters. In-vitro studies show that antimicrobial impregnated catheters loose their efficacy with time [70] but at least theoretically, these catheters would be effective at the most crucial time post-implantation. Clinical studies have shown that intravenous catheters impregnated with chlorhexidine and silver sulfadiazine or minocycline and rifampin are effective in reducing bacterial colonization of catheters with the data being somewhat controversial on reduction of catheter related blood stream infections [71, 72]. Antimicrobial impregnated peritoneal catheters have been studied in rats [73, 74]. In one study, after implantation, the exit sites of both control and impregnated catheters were inoculated with S. *aureus*. All of the control catheters developed colonization at the exit-site and intra-peritoneally seven days post-implantation. In the impregnated catheters, none had intra-peritoneal colonization while12.5% had colonization of the exit-site [73]. In another animal study, Trooskin and colleagues [74], peritoneal dialysis catheters with anionic antibiotic bonded to cationic surfactants, were found to be more resistant to colonization after exit site and intraluminal bacterial challenges. In a prospective randomized study of 86 patients, catheters which were bonded with cefoxitin were unable to show decrease in exit-site infections and peritonitis when compared with the control group [75]. Further refinement of this technique may make this approach effective in the future.

Favorable experience gained with alumina ceramic in orthopedic surgery, otorhinolaryngology, and dentistry inspired Amano et al. [76] to use alumina ceramic for a peritoneal catheter. In this catheter the part of the tubing designated to be contained within the sinus tract is replaced by a rigid alumina ceramic connector. Dog experiments with this material revealed only minimal skin down growth. Preliminary human experience was encouraging [76], but no long-term results have yet been published.

This chapter will describe in detail some of those catheters that are in current use, their insertion technique, postimplantation care, and long-term results. New, emerging techniques will be briefly reviewed.

Currently Used Chronic Peritoneal Catheters

The chronic peritoneal catheter is composed of an intraperitoneal and extraperitoneal portion. The latter comprises a tunnel within the body wall (intramural) and an external (outside the exit site) portion. The intraperitoneal and extraperitoneal portions differ in various catheters and there are many combinations of those. Figure 14.17 shows combinations of intraperitoneal and extraperitoneal designs of currently available chronic peritoneal catheters.

A survey conducted at the Annual Dialysis Conference in 2005 looked at the choice of peritoneal dialysis catheters and implantation techniques over the preceding year [77]. Worldwide, the Tenckhoff catheter was the most popular, used in 65% of patients, followed by the swan-neck catheter in 26% patients. The swan-neck catheter was used in 36% of patients in the United States and 49% in Europe. In this survey, no usage of the swan-neck catheter was reported from Canada, where almost three quarters of the catheters were Tenckhoff and the rest Toronto Western Hospital catheters. Mexico and Central America exclusively used Tenckhoff catheters. Over 90% of the catheters had two cuffs and 68% had coiled intraperitoneal sections. Surgical implantation was used for 72% of patients and 16% were peritoneoscopically placed [77].

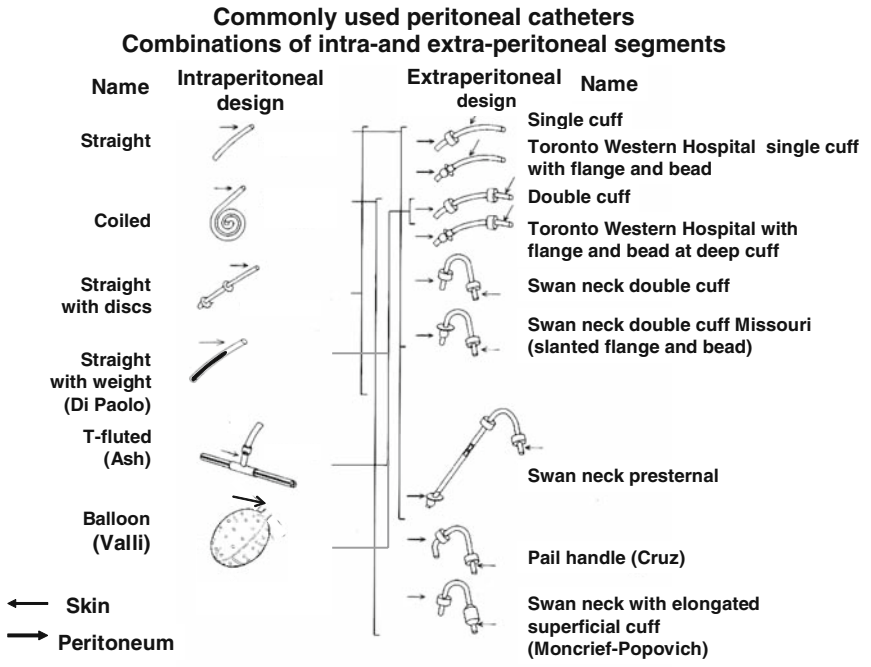

Fig. 14.17 Currently available chronic peritoneal catheters showing combinations of intraperitoneal and extraperitoneal designs. Modified and updated from [129]

Among the pediatric population in this survey, the Tenckhoff catheter was predominant (59%), with swan-neck catheters being used in 41% of patients. In Mexico and Asia the Tenckhoff catheter was used exclusively in children. The majority of the catheters were implanted surgically in this population as well [77]. A survey in 1994 had shown an increase in utilization of swan-neck catheters in the Unites States [78] and it now appears that Europe is following the trend. The swan-neck catheters are associated with fewer episodes of early outflow track obstruction and catheter migration but have not been shown to decrease peritonitis [1, 79]. The use of swan-neck catheters is recommended preferentially by the International Society of Peritoneal Dialysis [1]. The most commonly used catheters are described in detail below.

Straight and Coiled Tenckhoff Catheters

The catheter consists of silicone rubber tubing with a 2.6 mm internal diameter and a 5 mm external diameter (Figs 14.1 and 14.13). The catheter is provided with one or two polyester (Dacron®), 1-cm-long cuffs. The overall length of the adult straight double-cuff catheter is about 40 cm. The lengths of segments are as follows: intraperitoneal, about 15 cm; intercuff, 5–7 cm (intramural); external, 16 cm. The intraperitoneal segment has an open end and multiple 0.5-mm perforations at a distance of 11 cm from the tip. The coiled Tenckhoff catheter differs from the straight in having a coiled, 18.5-cm-long perforated intraperitoneal end. As mentioned above, the coiled catheter reduces inflow infusion "jet effect" and pressure discomfort. All Tenckhoff catheters are provided with a barium-impregnated radiopaque stripe to assist in radiological visualization of the catheter.

Swan-Neck Catheters

The swan-neck catheter is the second most commonly used catheter at present. Its design is based on a retrospective analysis of complication rates with Tenckhoff and Toronto Western Hospital catheters. This analysis showed that the lowest complication rates were with double-cuff catheters implanted through the belly of the rectus muscle and with both internal and skin exits of the tunnel directed downwards; however, the resulting arcuate tunnel led to frequent

Table 14.2 Swan-neck catheter features preventing complications

Exit/tunnel infection	Downward exit, double cuff, short sinus
External cuff extrusion	Permanent bend between cuffs
Intraperitoneal tip migration	Downward intraperitoneal entrance
Pericatheter leak	Insertion through the rectus muscle
Peritonitis	Decreased tunnel infections
Infusion/pressure pain	Coiled intraperitoneal tip

external cuff extrusion [50]. Swan-neck catheters feature a *permanent bend* between cuffs (Table 14.2) [80]. The catheter was dubbed "swan-neck" because of its shape. As a result of this design, catheters can be placed in an arcuate tunnel in an unstressed condition with both external and internal segments of the tunnel directed downwards. A downward-directed exit, two intramural cuffs, and an optimal sinus length reduce exit/tunnel infection rates. A *permanent bend* between cuffs eliminates the silastic resilience force or the "shape memory," which tends to extrude the external cuff. A downward-directed peritoneal entrance tends to keep the tip in the true pelvis, reducing its migration. Insertion through the rectus muscle decreases pericatheter leaks by promoting fibrous ingrowth into the Dacron® cuff. Lower exit/tunnel infection rates curtail peritonitis episodes. Finally, swan-neck catheters with a coiled intraperitoneal segment minimize infusion and pressure pain.

Swan-neck prototypes (Fig. 14.18) were designed in 1985 and were used briefly between August 1985 and April 1986. These catheters were made with 80° of arc angle and were inserted in a reversed U-shape tunnel with the incision at the top of the tunnel [81]. Only 27 of these catheters were inserted because we noted a tendency to cuff extrusions, which we considered a risk for exit infections [82]. Further observations confirmed our predictions. Cuff extrusion occurred in nine catheters and led to exit infections and finally to catheter removal. Initial excellent results with these catheters because of elimination of leaks and malfunctions were obviated later by high infection rates. Cuff extrusions resulted from resilience forces pushing on the external cuff due to an insufficient bend of the catheter and too long a distance between cuffs. We considered these catheters as suboptimal and discontinued their use in April 1986 [82, 83]. Based on this unfavorable observation the catheters were modified; the new catheters, swan-neck 2 and 3 catheters, had straight intraperitoneal segments. A major improvement was in the inter-cuff shape; the distance between cuffs was shortened from 8.5 to 5 cm in swan-neck 2 and to 3 cm in swan-neck 3 catheters and the bend was increased from 80° to 170–180° arc angle. The catheters were provided with short or long intraperitoneal segments, selected according to patient size and insertion site, to secure the catheter-tip position in the true pelvis [82, 84]. Because in several patients infusion pain occurred due to a "jet effect" and/or tip pressure on the peritoneum, we modified the intraperitoneal segment of the catheters, replacing a straight segment with a coiled one (swan-neck coiled). These catheters were introduced in January 1990 and within a month swan-neck straight catheters were phased out [83].

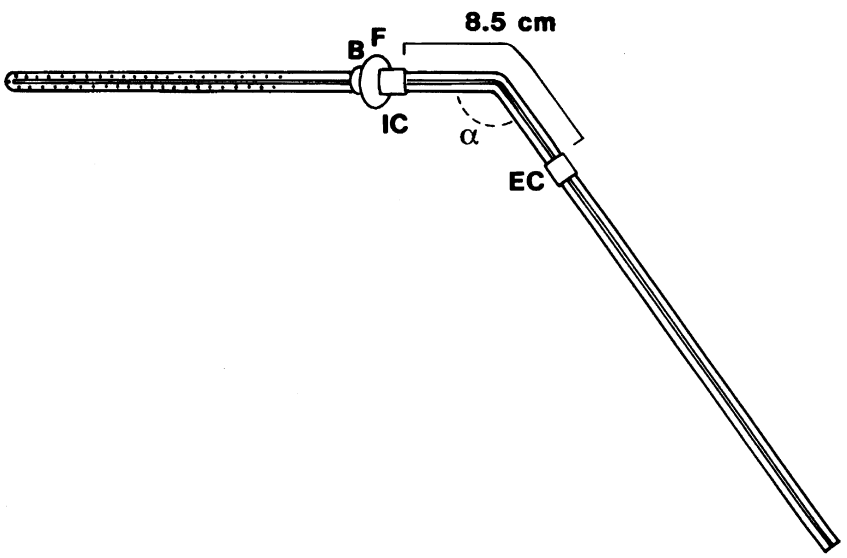

Fig. 14.18 Swan-neck Missouri prototype catheter. Arc angle = 180° – α = 80°. Cuff extrusions were common with these catheters because of insufficient bend and too long a distance between cuffs. We consider these catheters as suboptimal and we have not used them since April 1986

Swan-Neck Tenckhoff Straight and Coiled Catheters

The Tenckhoff type of the swan-neck peritoneal dialysis catheter is provided with two Dacron® cuffs. It differs from the double-cuff Tenckhoff catheter only by being permanently bent between cuffs. This type of catheter may be inserted at the bedside and does not require surgical insertion; however, a subcutaneous pocket and tunnel has to be created in the same way as for other swan-neck catheters. The intraperitoneal segment of the swan-neck coiled catheter is identical to that of the Tenckhoff coiled catheter [84]. All swan-neck catheters are manufactured by Covidien (Mansfield, MA 02048, USA).

Swan-Neck Missouri Straight Catheter

The swan-neck Missouri abdominal catheter has a flange and bead circumferentially surrounding the catheter just below the internal cuff; the flange and bead are slanted approximately 45° relative to the axis of the catheter. The catheters for left and right abdominal tunnels are mirror-images of each other. A swan-neck abdominal Missouri 2 abdominal catheter with a 5-cm inter-cuff distance is used in average to obese people (Fig. 14.19). A swan-neck abdominal Missouri 3 abdominal catheter with a 3-cm inter-cuff distance is used in lean to average persons [84].

Swan-Neck Missouri Coiled Catheter

The intraperitoneal segment in all swan-neck coiled catheters is 34 cm from the bead to the tip of the coil. Swan-neck abdominal Missouri 2 coiled abdominal catheters with the 5-cm inter-cuff distance (Fig. 14.19) are used in average to obese people. Swan-neck abdominal Missouri 3 coiled catheters with 3-cm inter-cuff distance are used in lean to average persons. The catheters for left and right tunnels are mirror-images of each other [84]. The overall survival values of straight and coiled swan-neck Missouri abdominal catheters are not significantly different, but none of the

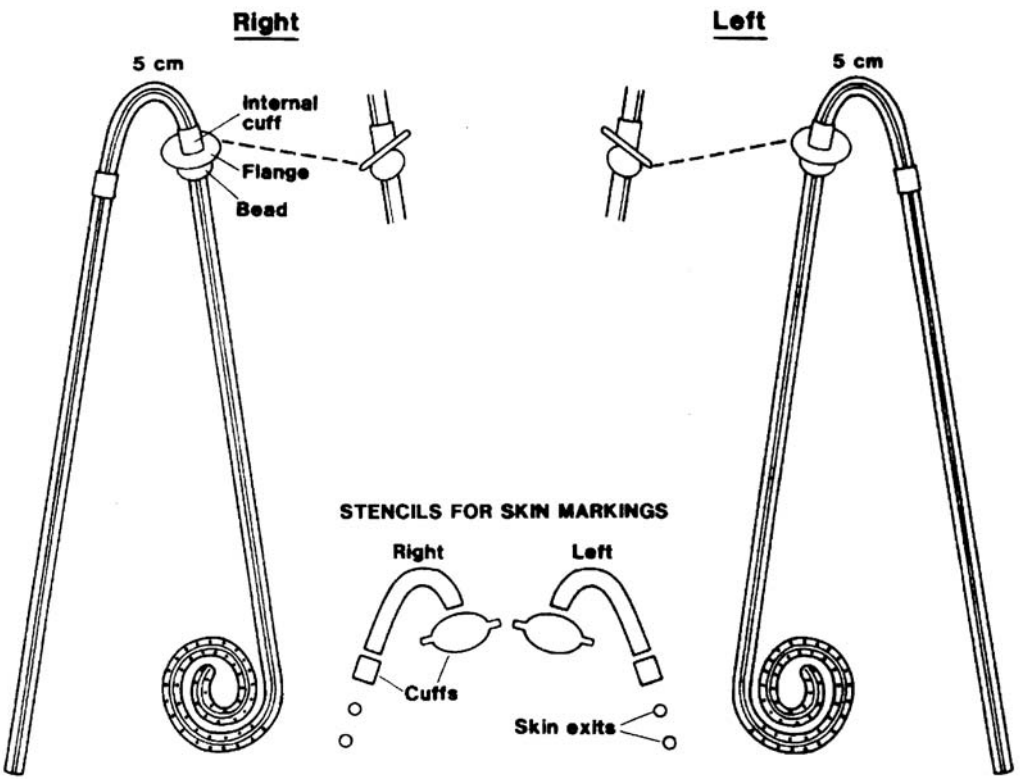

Fig. 14.19 Swan-neck Missouri 2 coiled (curled) catheters and stencils. Swan-neck Missouri 2 catheters have 5-cm intercuff distance and intraperitoneal length of 32 cm from the bead to the tip. The flange and bead are slanted approximately 45° relative to the tubing axis. The catheters for left and right tunnels are mirror-images of each other. The stencil follows exactly the shape of the intramural segment. The stencil can be flipped to be used for right or left catheter. The holes for exit-site markings are located 2 and 3 cm from the cuff. A 3-cm mark is used for average or obese persons, a 2-cm mark is suitable for lean or average persons

patients experienced infusion or pressure pain with coiled catheters, whereas this complication occurred in several patients who had catheters with straight intraperitoneal segments [83]. Swan-neck catheters are also available in smaller sizes for children and infants.

Swan-Neck Presternal Catheter

Potential advantages of exit location in the chest instead of in the abdomen are shown in Table 14.3. The chest is a sturdy structure with minimal wall motion; the catheter exit located on the chest wall is subjected to minimal movements, decreasing chances of trauma and contamination. Also, in patients with abdominal ostomies and in children with diapers, a chest exit location reduces the chances of contamination. Moreover, a loose garment is usually worn on the chest and there is thus less pressure on the exit. Surgical experience indicates that wounds heal better after thoracic surgery than after abdominal surgery; this may, in part, be related to less chest mobility. Obese patients have higher exit-site infection rates and a tendency to poor wound healing, particularly after abdominal surgery. The subcutaneous fat layer is much thinner on the chest than on the abdomen. If fat thickness *per se* is responsible for quality of healing and susceptibility to infection then chest location may be preferred for obese patients. All these favorable factors, together with easy exit-site care using a magnifying mirror, significantly reduce exit-site infections. The location of the exit site on the chest is particularly advantageous in small children because of the greater distance from diapers and is subjected to fewer traumas during crawling/creeping. The catheter is also advantageous for psychosocial reasons. A chest exit location allows a tub bath without the risk of exit contamination. Although the exit site can be located in the presternal or parasternal area we will usually refer to this catheter as presternal for simplicity. However, implantation directly over the sternum should be avoided to prevent catheter damage during median sternotomies used for cardiac surgery. A long catheter tunnel, combined with three cuffs, may curtail pericatheter bacterial penetration into the peritoneal cavity, thus reducing the incidence of peritonitis [3, 84, 85].

To accommodate these principles we modified the swan-neck peritoneal catheter to have an exit on the chest but preserving all advantages of the swan-neck abdominal Missouri coiled catheters, minimizing catheter obstruction, cuff extrusion, pericatheter dialysate leak, and infusion pain. A major difference from the swan-neck abdominal Missouri catheter is in the length of the subcutaneous tunnel. The catheter (Fig. 14.20) is composed of two silicone rubber tubes, which are cut to an appropriate length and connected end to end at the time of implantation [84, 85]. Figure 14.14 shows the catheter in relation to the torso after implantation. The implanted lower (abdominal) tube constitutes the intraperitoneal catheter segment and a part of the intramural segment. The upper or chest portion of the tube constitutes the remaining part of the intramural segment and the external catheter segment. The lower tube is identical to the swan-neck abdominal Missouri catheter, with the exception that it is not bent and does not have a second cuff. The proximal end of the lower tube is straight and with a redundant length to be trimmed to the patient's size at the time of implantation. A titanium connector, provided in a package, is to be used to connect the two components at the time of implantation.

Table 14.3 Potential advantages of the swan-neck presternal catheter compared to the swan-neck Missouri catheter

Attribute	Advantage	Explanation
Exit on the chest	Decreased risk of exit infection	Good immobilization
		Good wound healing
		Loose garment/less pressure
		Easy exit-site care
		Less fat thickness
		Far from ostomies*
		Far from wet diapers**
		Less trauma with creeping**
	Psychosocial	Better body image for some patients
		Easy exit-site care
		May take tub bath without risk of exit contamination
Three cuffs	Decreased risk of peritonitis	Strong (triple) barrier
		Long tunnel, long distance for bacterial penetration

*In patients with ostomies.
**In small children

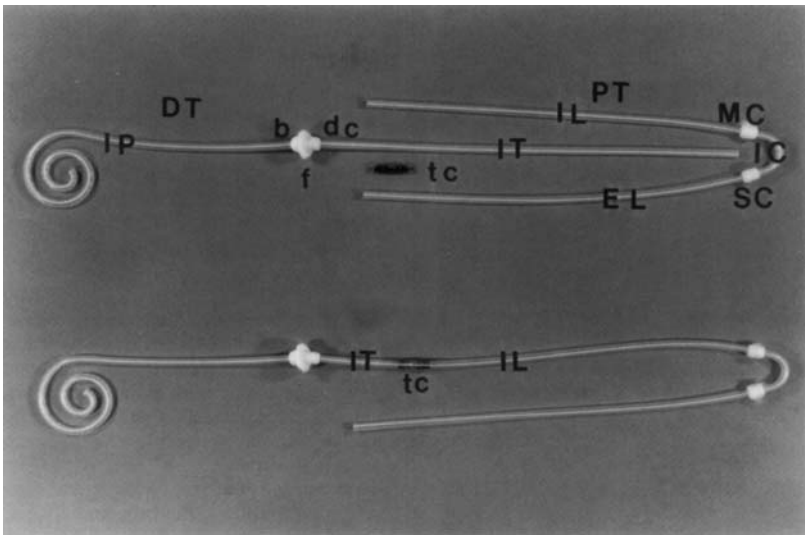

Fig. 14.20 Swan-neck presternal catheter: two tubes of the swan-neck presternal peritoneal catheter before (top) and after (bottom) connection. Both tubes and bead are made of silicone rubber moulded in the shapes as shown. A flange and all cuffs are made of woven polyester fibers. Proximal (upper, chest) tube (PT) consists of an intra-tunnel limb (IL), medial (center) cuff (MC), inter-cuff segment (IC), superficial cuff (SC), and external limb (EL); 1–2 cm of the external limb adjacent to the superficial cuff is intended to be in the sinus tract of the tunnel (from the cuff to the exit). Distal (abdominal, lower) tube (DT) consists of an intra-tunnel segment (IT), deep (distal, preperitoneal) cuff (dc), flange (f), bead (b), and intraperitoneal segment (IP). After implantation (bottom), the intra-tunnel limb (IL) of the chest tube and the intra-tunnel segment (IT) of the abdominal tube are trimmed to the size of the tunnel and coupled with titanium connector (tc)

The upper tube carries two porous Dacron® cuffs, a superficial and middle or central cuff, spaced 5 cm apart. The tube between the cuffs has a permanently bent section defining an arc angle of 180°. The distal lumen of the upper tube communicates with the proximal lumen of the lower tube through the titanium connector. The tubing grip of the titanium connector is so strong that the two parts of the catheter, especially after connection reinforcement with monofilament or braided suture, in practice cannot separate spontaneously in the tunnel [86]. The swan-neck presternal catheter is available for children and infants [87]. Tubing diameter is smaller for pediatric patients.

Moncrief–Popovich Catheter

This catheter is a modified swan-neck Tenckhoff coiled catheter (Fig. 14.17) with a longer subcutaneous cuff (2.5 cm instead of 1 cm). This catheter is most commonly used in conjunction with the Moncrief–Popovich implantation technique (see below).

Radiopaque Stripe

The slanted flange and bead, and bent tunnel segment, require that the swan-neck abdominal Missouri abdominal and Toronto catheters for right and left tunnels be mirror-images of each other. To facilitate recognition of right and left Toronto and Missouri catheters, each catheter has a radiopaque stripe in front of the catheter (Fig. 14.19). In a swan-neck presternal catheter the stripe also facilitates proper alignment of the lower and upper tubes. The stripe is also useful during insertion and postimplantation care, facilitating recognition of catheter twisting. Because of this last feature Tenckhoff-type catheters are also provided with the stripe. Right and left swan-neck Tenckhoff catheters differ only with respect to the position of the stripe. Unlike swan-neck Toronto and Missouri catheters, with the slanted flange, the swan-neck Tenckhoff catheter may be implanted on either side. In this case the stripe may be positioned in the back of the catheter. Nevertheless, to retain uniformity of the stripe position anterior it is recommended that swan-neck Tenckhoff catheters be inserted with the corresponding tunnel direction (right tunnel with right catheter, left tunnel with left catheter).

Other Catheters

Catheters used in small numbers, such as recently designed catheters with one-center experience (T-fluted [45], self-locating [48]) and those used in smaller numbers (Cruz [51, 88], Toronto Western Hospital [40], Life-cath or Column disc [43], Valli [41, 42] and Gore-Tex [38] catheters), will not be described in detail. Readers are referred to the original publications.

Accessories for Implantation of Catheters

Stencils

Stencils have been developed for skin markings to facilitate creation of proper tunnels for swan-neck catheters [84]. Stencils are for swan-neck abdominal Missouri 2 (Fig. 14.19), swan-neck abdominal Missouri 3, and swan-neck abdominal Tenckhoff catheters. The stencils follow exactly the shape of the intramural segments of the catheters and the catheter tunnels must follow the shape of the catheters exactly as designed to maximize the advantages of this design. The stencils can be flipped to be used for right or left catheters. The holes for exit-site markings are located 2 and 3 cm from the superficial cuff. A 3-cm mark is used for average or obese persons; a 2-cm mark is suitable for lean or average persons. Stencils for swan-neck Tenckhoff catheters also reflect precisely the shape of their intramural segments.

Stiffening Stylet

A 62-cm-long stiffening catheter guide is used to facilitate catheter insertion into the true pelvis. During insertion, approximately 1 cm of catheter is left beyond the tip of the catheter guide to protect the intestine. The catheter resumes its natural coiled shape after the stylet is removed [84].

Tunneling Devices

Tenckhoff Trochar

Tenckhoff developed a special trochar for bedside insertion of cuffed catheters into the peritoneal cavity (Fig. 14.12). The trochar (available from Covidien, Mansfield, MA 02048, USA) consists of a sharp, stainless-steel stylet; a solid, wide, open-ended barrel; and two side-pieces with handles [89].

Scanlan Tunneler/Bard Tunneler

A Scanlan (Scanlan International, St. Paul, Minnesota, USA) or Bard tunneler (Bard Peripheral Vascular Division, Inc., Tempe, Arizona, USA) is used during swan-neck presternal catheter implantation to create a tunnel extending from the abdominal wall incision to the presternal or parasternal area. A tunneler that will accommodate vascular grafts up to 8 mm is suitable for presternal catheter implantation. The tunneler, developed for tunneling vascular grafts, consists of an outer sheath with a blunt tip, and a stiff rod with handle. The stiff metal rod serves to stiffen the tunneler as it is pushed through the subcutaneous tissue and a spring clamp or suture hole at the tip is used to grasp or attach the upper tubing and pull it through the sheath [90].

Exit Trochar

The catheter tunnel extending from the superficial cuff to the skin exit should have a diameter close to that of catheter tubing. Thus, the last portion of the tunnel (from external cuff to the exit) should be made with a piercing trochar, e.g., the Faller trochar (Covidien, Mansfield, MA 02048, USA) or a 3/16 inch (4.76 mm, F15) trochar designed for the Hemovac system (Zimmer Mfg. Co., St. Louis, Missouri, USA) or the trochar from a 19 Blake drain (Ethicon Inc. a Johnson & Johnson Company, Somerville, New Jersey, USA) of external diameter similar to that of the catheter tubing [84, 90].

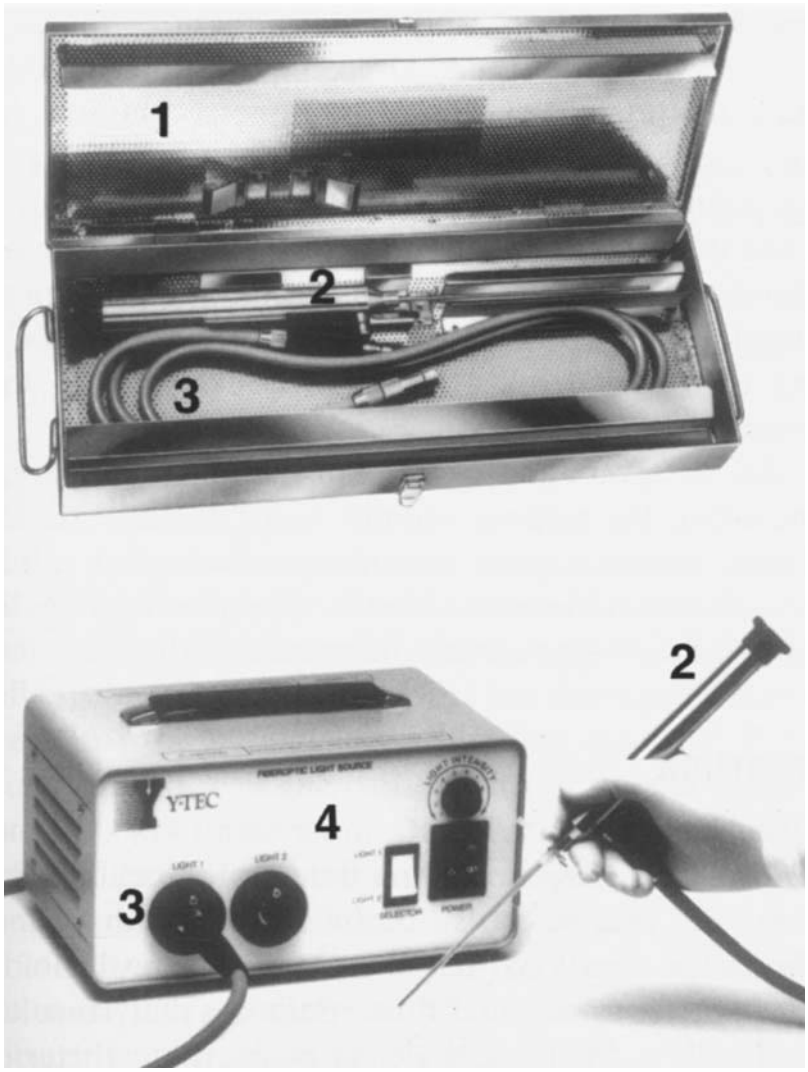

Fig. 14.21 Components for the peritoneoscopic catheter insertion. Above: the sterilization tray (1); the Y-TEC® scope (2); and the light guide (3). Below is the Y-TEC® light source (4), with the scope (2), and light guide (3)

Peritoneoscopic Equipment

The basic equipment (Fig. 14.21) required for peritoneoscopic insertion (manufactured and distributed by Medigroup, North Aurora, Illinois, USA) includes a 2.2-mm diameter, 15-cm long Y-TEC peritoneoscope with a 2.5-mm steel cannula with internal trochar and a spiral-wound Quill catheter guide surrounding the cannula [91, 92].

Seldinger (Guidewire) with Peel-Away Sheath Equipment

The essential instruments (Fig. 14.22) for this technique include a guide needle, attached to a syringe, a Seldinger guidewire, and a tapered dilator with surrounding scored peel-away sheath [93–96]. The necessary equipment and videos can be obtained through Cook Critical Care, Division of Cook Inc., Bloomington, Indiana, USA.

Titanium Connectors, Tyton Ties, and a Tension Tool

After implantation, the catheter must be connected to the peritoneal dialysis set. A titanium connector serves this purpose. A single-piece connector shown in Fig. 14.23 is simply inserted into the end of the external catheter tubing.

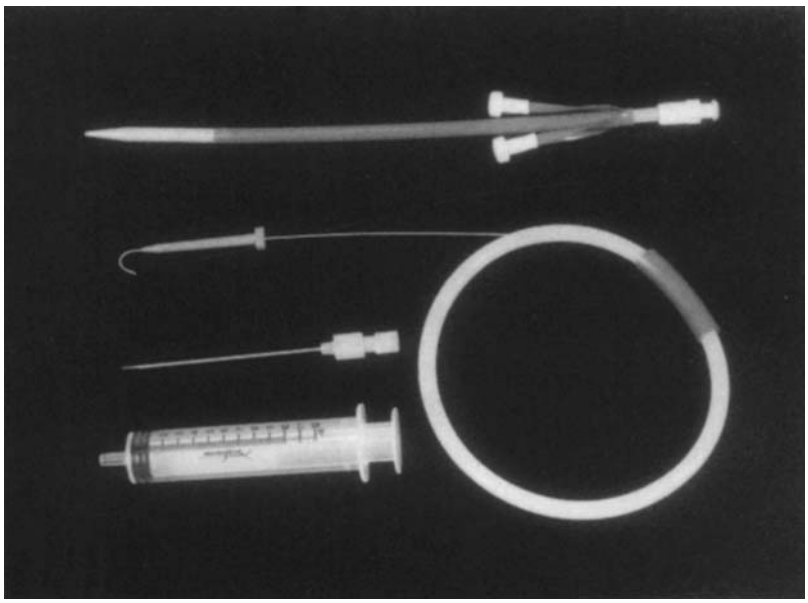

Fig. 14.22 Equipment for guidewire insertion method. From the top: peel-away sheath with dilator, guidewire, needle, and syringe

The external part is equipped with a female Luer lock adapter and sealing cap. The intracatheter adaptor is barbed and its external diameter is slightly larger than the internal diameter of the tubing to avoid accidental disconnection; however, this titanium connector has been associated with numerous instances of spontaneous separations. Tyton ties and a tension tool (Tyton Corporation, Milwaukee, Wisconsin, USA) routinely used to secure bundles of electrical wirings, and available in department stores, may be used to prevent disconnection of the titanium adaptor from the tubing. A 4-inch (100-mm) tie is placed around the distal end of the catheter over the adapter. Care is taken to place the tie in the groove between adapter ridges and not over a ridge. Then the tie is tightened with the tension tool that also trims the excess length. The locking segment is located at the stripe, which will be positioned at the front of the patient (Fig. 14.23). This keeps the added bulk away from the patient [84, 97, 98].

A recently introduced two-piece adapter (Baxter Healthcare Corporation, Deerfield, Illinois, USA), shown in Fig. 14.24, is very safe and no instances of accidental connector disengagements have been reported. The only disadvantage of this design is the substantially higher price.

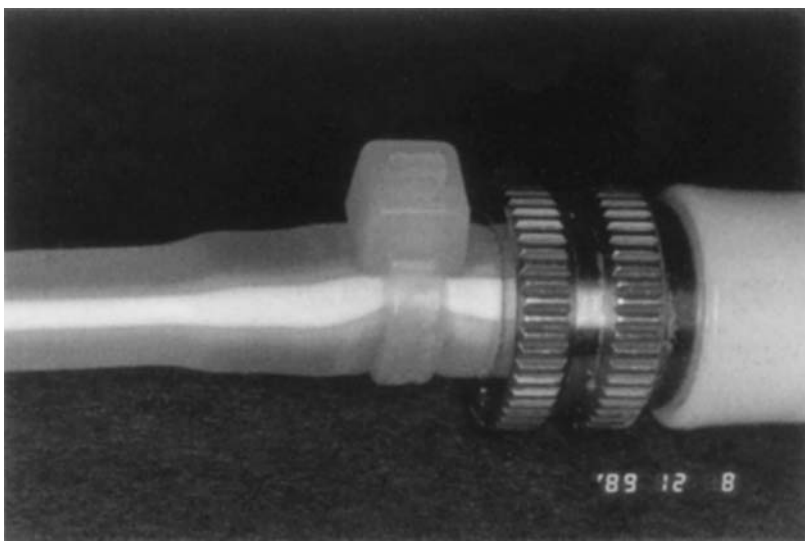

Fig. 14.23 A single-piece titanium adaptor with a barbed connector in the catheter tubing and a male Luer lock connector attached to the female connector of the extension tube. The nylon tie is in place over the catheter/barbed connector junction. The locking segment is over the stripe and will be away from the patient's skin

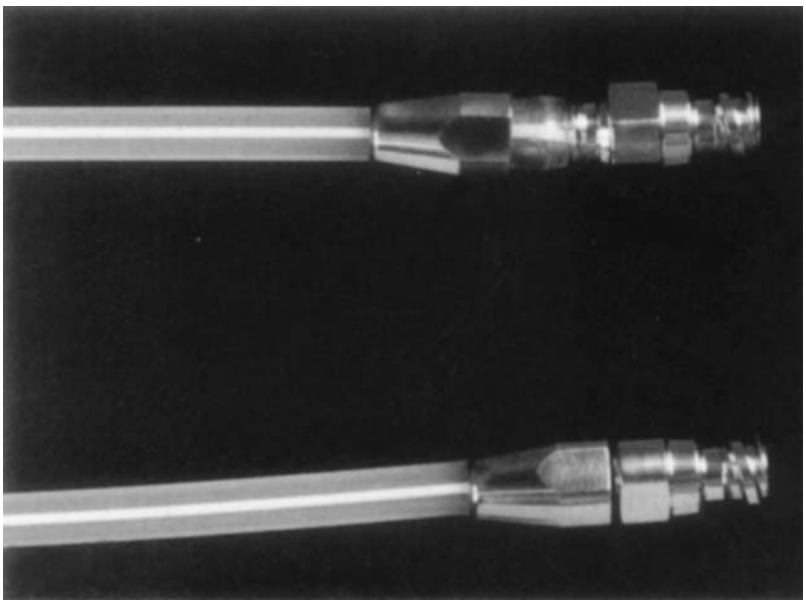

Fig. 14.24 A two-piece adapter (locking titanium adapter – Baxter) with two parts disengaged (upper), with adaptor inserted into the external end of the catheter and after the two pieces are screwed together and tightened (lower)

Insertion of Rigid Catheters

Rigid Catheters for Acute Dialysis

The two most widely used rigid catheters in North America are the Stylocath (Abbott Laboratories, North Chicago, Illinois, USA) and the Trocath (Baxter Healthcare Corporation, Deerfield, Illinois, USA).

Preinsertion Patient Assessment and Preparation

When the need to start peritoneal dialysis is urgent, one may elect to access the peritoneal cavity through a rigid catheter. This catheter can be inserted at the bedside, with minimal preparation. Equipment required for paracentesis is all that is needed.

Bedside insertion *should not* be offered to patients who are extremely obese, or have had previous abdominal surgery, since abdominal adhesions increase the risk of unintentional viscus perforation. In addition, this approach should only be done in children by an experienced pediatric nephrologist or a nephrologist with a pediatrician in attendance. If a nephrologist places the catheter a surgeon should be on stand-by, in case of complications. The patient should receive preoperative sedation and have nothing to eat or drink at least 12 h prior to the procedure.

All observers and persons in the immediate area, including the patient, should wear surgical masks. Those patients who experience discomfort while completely supine should raise their heads slightly. In conscious patients it may be useful to familiarize them with the Valsalva maneuver. The operator and assistant(s) should "scrub, gown and glove." A "circulating" nurse should be present to assist.

Insertion Technique

Using sterile precautions, a small stab wound (2–3 mm) is made in the midline under local anesthesia, 2–3 cm below the umbilicus. The stab wound should be small so that the abdominal wall holds the catheter firmly and thus minimizes dialysis solution leak. With the stylet in place, the catheter is introduced through the abdominal wall by a short thrust, or preferably with a rotary motion. The operator will recognize the loss of resistance as a "pop" as soon as the peritoneal cavity is entered. While the catheter is being thrust through the abdominal wall its tip is directed towards the coccyx. Because successful perforation of the abdominal wall for introduction of the catheter requires a sensitive "feel" for the pressure applied, prior infusion of 2–3 L of dialysate will distend the abdomen, which in turn will facilitate this maneuver. Some infuse 2 L of dialysis fluid via a small-gauge needle prior to stylet puncture. A cooperative patient can also assist successful perforation by voluntarily tightening the abdominal musculature.

Once the peritoneal cavity has been entered the stylet is withdrawn a few centimeters and the catheter is advanced deep into the pelvis. If the operator encounters resistance while the catheter is being advanced, or if the patient

complains of pain, the advance in this direction should be stopped and another direction tried. If this is still not possible, the operator may infuse 2–3 L of dialysis solution into the peritoneal cavity if this has not been done. This can be via the catheter if the holes in the distal end are within the abdominal cavity. This infusion accomplishes two important objectives: first, it facilitates recognition of the "true" intraperitoneal space; second, dialysis solution in the peritoneal cavity reduces the likelihood of viscus perforation by moving the intra-abdominal contents away from the advancing catheter.

After one or two good in-and-out exchanges, the catheter is firmly secured to the skin with the aid of a metal disc.

Complications

Table 14.4 shows complications of rigid catheter insertion. After catheter implantation, bloody effluent appears after the first exchange in approximately 30% of cases [99, 100]. This bleeding (usually minor) comes from the small vessels in the abdominal wall. After three or four exchanges, bleeding usually stops, unless the procedure has damaged a major vessel or the patient has a bleeding disorder. Pressure applied over the catheter insertion site usually controls minor bleeding. If the bleeding is copious it may obstruct the catheter; in this event it, is a common practice to add 1,000 units of heparin to each liter of dialysate to minimize the risk of obstruction. Intraperitoneal heparin is not absorbed in sufficient quantities to influence systemic coagulation.

Dialysis solution leak is encountered in 14–36% of patients after rigid catheter insertion [99–101]. Frequent manipulation of the catheter to improve drainage increases the risk of dialysis solution leak from the catheter-exit site. Such leaks may also occur when the catheter is not properly secured to the skin. The risk of external leak is higher in elderly or debilitated patients who have lax abdominal walls. The presence of a large intra-abdominal mass, such as a polycystic kidney, may raise the intra-abdominal pressure to high levels and promote dialysis solution leak around the catheter after the standard 2-L volume has been instilled.

Fluid may extravasate into the abdominal wall, particularly in patients who have had a previous abdominal operation or multiple catheter insertions. This complication usually results from tears in the peritoneum or represents an infusion of dialysate into the "potential" space between the layers of abdominal wall. Uncommonly, dialysis fluid may enter the pleural cavity [101–109]. In such cases, peritoneal dialysis is usually discontinued and the patients are switched to hemodialysis. Acute hydrothorax results from either a traumatic or a congenital defect in the diaphragm.

Inadequate drainage is frequent during initial dialysis, and may be due to one or more of the following factors: loss of siphon effect, one-way obstruction, and/or incorrect placement of the catheter. One-way (outflow) catheter obstruction may have multiple causes. Fibrin or blood clots may be trapped in the catheter and block the terminal holes, especially when dialysis is complicated by major hemorrhage or peritonitis. Poor outflow may also reflect extrinsic pressure on the catheter from adjacent organs such as a sigmoid colon full of feces or a distended bladder. Omental wrapping is likely if the catheter is misplaced into the upper abdomen.

Occasionally, accidental penetration of the extraperitoneal space by the catheter may cause poor drainage. In such a situation, continued infusion produces further dissection, and the fluid may become trapped and is no longer available for drainage. Loculation of fluid, another cause of poor drainage, is encountered in patients who have had previous intra-abdominal operations or peritonitis. Such loculation, caused by adhesions, not only diminishes the surface area available for dialysis but may seriously reduce ultrafiltration capacity. The incidence of this complication is low, varying between 0.5 and 1.3% [110–118]. Abdominal distension and even respiratory compromise may develop in some patients with inadequate drainage.

Poor ultrafiltration may leave the patient hypervolemic and on occasions rapid hypertonic exchanges can cause excessive fluid removal leading to hypovolemia and hypotension. Rapid exchanges may also be complicated by sodium sieving leading to hypernatremia [100, 115, 119]. Acute peritoneal dialysis may be complicated by significant protein losses in dialysate ranging from 10 to 20 g/day [118–120].

Table 14.4 Complications of rigid catheter insertion

Bleeding
Dialysis solution leak
Poor drainage
Extraperitoneal space penetration
Viscus perforation
Peritonitis
Abdominal pain
Loss of rigid catheter in the peritoneum

Perforation or laceration of internal organs during bedside insertion of a catheter has been frequently reported. Lacerated or perforated organs include the bowel, bladder, liver, a polycystic kidney, aorta, mesenteric artery, and hernia sac [100, 112, 114, 121–123]. Abdominal distension due to paralytic ileus or bowel obstruction may predispose the patient to bowel perforation. Those who are unconscious, cachectic, or heavily sedated are also at high risk. Clinical evidence of bowel perforation includes sudden, sharp, or severe abdominal pain followed by watery diarrhea, and poor drainage of dialysis solution, which may be cloudy, foul smelling, or mixed with fecal material. Such a situation requires prompt removal of the catheter, and allowing the perforation to seal off completely in about 12–24 h. An exploratory laparotomy may be necessary and surgical consultation should be obtained.

Abdominal pain may be encountered in as many as 56–75% of patients with the first use of the catheter [100, 110, 118]. There are many causes of abdominal pain, but catheter-related pain occurs when it impinges on any of the viscera. Pain may occur during inflow and outflow of dialysis solution and also when the solution is dwelling. Inflow pain is often related to the acidity of the solution, its temperature, the jet effect from a straight catheter, or distension of tissues around the catheter. These complications can be dealt by adding sodium bicarbonate (5-25 mEq/L), warming the solution or adjusting the infusion rate [119]. Outflow pain is due to entrapment of omentum in the catheter during the siphoning action of fluid drainage. Constant pain during dialysis indicates pressure effects on intra-abdominal organs and often produces continuous rectal or low-back pain. This complaint calls for an adjustment in catheter position.

The incidence of peritonitis, when the stylet catheter is used, increase with time the catheter is left in the abdomen [124]. Phu et al [125] studied veno-venous hemofiltration and acute peritoneal dialysis with a rigid catheter for infection-associated acute renal failure. He reported an incidence of 42% of cloudy dialysate with only one patient having confirmed peritonitis. Chitalia et al [120] reported 5 episodes of peritonitis among 87 patients treated for hypercatabolic acute renal failure with either continuous equilibrating peritoneal dialysis or tidal peritoneal dialysis with the abdomen accessed with a stylet catheter.

Loss of a part or the entire rigid catheter has been reported following its manipulation with the trochar in place [113, 114, 126–128]. The distal end of the catheter may be amputated after intra-abdominal kinking of the catheter, followed by manipulation. However, the presence of broken catheters within the abdominal cavity may not cause symptoms or ill-effects. During laparoscopy, broken catheters have been found lying freely in the peritoneal cavity without causing a peritoneal reaction, or have been found walled off by mesentery without an inflammatory reaction. On routine postmortem examination, Stein [128] discovered such a catheter in a patient who had previous peritoneal dialysis. Exploration to retrieve the catheter maybe unnecessary because laparotomy may be more hazardous than leaving the catheter in a severely ill patient. Laparoscopic retrieval may be considered and likely will be tolerated in almost all patients. The incidence of catheter loss into the peritoneal cavity has been greatly reduced since the introduction of a design which incorporates a metal disc with a central hole; this not only allows the catheter to pass through the abdominal wall but also holds the catheter snugly to the skin of the abdominal wall.

Insertion of Soft Catheters

Because of the high frequency of dialysis solution leak, and poor drainage necessitating frequent catheter manipulation and resultant peritonitis with the use of rigid catheters, some centers prefer to insert a single- or double-cuff Tenckhoff catheter for treatment of acute renal failure. Tenckhoff recommended use of a single-cuff catheter for acute cases [1]. For treatment of chronic kidney disease, only soft catheters are used.

Patient Preparation

Acute Dialysis

Patient assessment and preparation before soft catheter implantation for treatment of acute renal failure is the same as that before rigid catheter insertion.

Chronic Dialysis

Patient preparation before catheter implantation for treatment of chronic kidney disease is more elaborate [1, 84, 97, 129, 130]. Immediately prior to surgery, chest and/or abdominal hair should be removed with an electric clipper. Prophylactic antibiotics prior to implantation are recommended.

Abdominal Exit

The belt line of a patient is identified, preferably in the sitting or standing position, with slacks or pants as usually worn [1, 129]. Depending on the size and shape of the abdomen, presence of previous scars, right- or left-handedness, and patient's preference, the tunnel is marked using the stencil (available with swan-neck catheters) in such a way that the exit hole would be created at least 2 cm from the belt line. Skin markings may be made with any good surgical marker.

Women usually wear a belt above the umbilicus; hence stencils are often marked below the belt line in female patients. The catheter should not be subjected to excessive motion with patient activities, and there should not be pressure on the tunnel when the patient bends forward. In obese people, with pendulous abdomens, it is mandatory to insert the catheter above the skin-fold so they can see the exit for its care. Men usually prefer a belt line below the umbilicus and there may not be enough space below the belt line; therefore a stencil is generally marked above the belt line in male patients. The label of the chosen catheter type is written on the belly of the patient. A band with the catheter label is also attached to the patient's left wrist.

Enemas are no longer recommended. Instead, the patient should take a shower if able. Skin markings may require remarking if they become faint after a shower. Antibiotic prophylaxis prior to catheter insertion is recommended and is discussed in a subsequent section of this chapter.

Presternal Exit

Depending on the size of the patient, the abdominal cuff and flange location is marked over the rectus muscle [90]. To secure the catheter-tip position in the true pelvis, but without an excessive pressure on the pelvic peritoneum, the position of the cuff should be above or at the level of the umbilicus in all persons. To determine a preferred position of the deep cuff, a coiled catheter tip is placed on the pubic bone and the cuff position is marked. On the chest, a superficial cuff is marked at the second or third intercostal spaces and the exit 3 cm from the cuff in the presternal or parasternal area. It is preferable not to cross the midline in patients likely to have heart surgery. Care is taken to avoid an exit site too close to bra lines in females. Prophylactic antibiotics, shower, and bowel prep are used in the same way as for abdominal exit.

Catheter Preparation

Immediately before implantation, the catheter is removed from the sterile peel pack and immersed in sterile saline. The porous Dacron® cuffs and Dacron® flange are gently squeezed under saline to remove air [84, 90, 131]. Thoroughly wetted cuffs provide markedly better tissue ingrowth compared to unwetted, air-containing cuffs [84, 90].

Implantation Method

Blind (Tenckhoff Trochar)

At the bedside, a sterile procedure must be strictly followed while inserting the catheter. A 2–3 cm incision is made in the skin at the insertion site (e.g., the midline 2 cm inferior to the umbilicus). This places the site of entry at the linea alba, a point of minimal vascularity and tissue resistance [92]. The lateral margins of either rectus muscle are alternative sites because they are also relatively avascular. It should be remembered that the placement through the belly of the rectus muscle using blind insertion may cause injury to the inferior or superior epigastric artery.

Through the skin incision the wound is deepened to the linea alba with blunt dissection using a curved hemostat. At this time, an "anchoring" suture is inserted in the fascia. The peritoneal cavity is entered with a "priming needle" (a "catheter over a needle," venicath-type needle, or a stylet peritoneal catheter) into the superior aspect of the wound and through the linea alba. One must take care to ensure "intraperitoneal" placement of all hole outlets of the priming device. If the parietal peritoneal membrane is separated from the preperitoneal tissue this will result in "preperitoneal" infusion of dialysis fluid and make impossible any further intraperitoneal infusion of dialysis fluid by this method. Furthermore, the expansion of the preperitoneal "pocket" is extremely painful. When dialysis solution infusion produces pain, the operator should suspect preperitoneal instillation; however, the heavily sedated or anesthetized patient may not be able to voice an objection. At this time poor dialysis solution inflow may also indicate that hole outlets are lodged in a preperitoneal position, although one might also anticipate a moderate restriction of flow in any case, given the relatively small lumen of the access catheter.

Following sterile connection of the administration tubing to the priming device, 2–3 L of dialysis solution are infused into the peritoneal cavity, until the patient feels distended. While dialysate is being instilled to the desired volume, the Tenckhoff catheter should be "prepared" by wetting it with a small volume of normal saline. Air from the cuffs is removed by squeezing. A wetted stiffening stylet is inserted into the catheter, thus straightening and "stiffening" it to permit introduction of the catheter into the Tenckhoff trochar, and beyond it into its correct intra-abdominal position.

It is useful to predilate the linea alba with a smaller trochar or dilator rather than a needle, thereby facilitating introduction of the larger Tenckhoff trochar. With firm but gentle pressure, and a twisting action, the trochar with its pointed stylet in place (Fig. 14.12) is pushed into the peritoneal cavity via the small perforation. Immediately after the resistance ceases (indicating entrance into the peritoneal cavity), the obturator is removed. The true intraperitoneal placement should be recognized by the "welling-up" of dialysis solution into the barrel of the trochar. If the operator has instilled enough dialysis solution during the priming procedure, he/she should insert the trochar until its wider portion comes to rest on the linea alba. This portion should not enter the peritoneal cavity, thus keeping the perforation at the desired diameter. This larger barrel is designed not only to accept the Tenckhoff catheter, but it also allows for the passage of the Dacron® cuffs.

The catheter is threaded on a stiffening stylet. About 1 cm of catheter is left beyond the tip of the stylet to protect the intestine. Proper placement of the catheter in the pelvis will greatly facilitate siphon drainage. During this phase of insertion, certain details, although they may seem trivial, if not attended to with care may produce unfavorable results. For example, as the catheter is introduced into the trochar on its way to the abdominal cavity, the tip should be passed smoothly beyond the trochar. Careful, gentle, and angular movement of the trochar and stiffened catheter (adjusting its intra-abdominal position and relationship to abdominal contents) may be needed to achieve easy passage of the catheter deep into pelvis.

Once the catheter has completed its "internal" course, the detachable trochar barrel should be removed, leaving the split side-pieces *in situ* for easier manipulation until the final positioning is satisfactory. At this point the stiffening stylet should be removed while the operator holds the catheter firmly in place. Once the desired depth of placement is achieved, the remaining catheter is "fed" into the peritoneal cavity while slowly withdrawing the stiffening stylet until the preperitoneal (inner or deep) Dacron® cuff comes to rest on the linea alba. Then the trochar is separated into its two longitudinal sections and withdrawn, leaving the catheter cuff in proper position. The ideal location for the internal cuff is at the preperitoneal level. However, if the catheter is intended for a short-term use until the patient recovers from an acute renal failure event, the location of deep cuff at the preperitoneal level is not as critical as in the case of long-term use. The Dacron® cuff must not be left positioned in the peritoneal cavity.

Catheter patency is tested in the same manner described in the surgical procedure. When the function is deemed satisfactory the catheter is secured in place to the linea alba with an anchoring suture before preparing for the creation of the subcutaneous tunnel towards the proposed exit site.

After choosing the catheter exit site, a stab wound (not an incision) is made using a blade, taking care to penetrate only the skin. The opening should be just the size of the catheter. Choose a site that will permit the creation of a tunnel of an appropriate length and shape of the catheter. A subcutaneous tunnel is created using a malleable uterine sound or the Faller trochar, being careful to manipulate the catheter gently. For the swan-neck Tenckhoff catheter, the tunnel must follow the skin marking made prior to the insertion. The outer cuff should be positioned approximately 2 cm from the skin exit. The recommended method for tunnel creation for the swan-neck Tenckhoff catheter is to make a superior subcutaneous pocket as described for surgical insertion (see below) and penetrate the exit with the piercing trochar. No sutures are used at the exit site. The titanium connector is then inserted into the end of the catheter. The skin of the insertion wound is sutured, and appropriate surgical dressings applied. Dressings are applied for at least 1 week while leaving an accessible length of catheter to permit the catheter to be handled without disturbing the dressings.

Peritoneoscopic

The use of peritoneoscopy for peritoneal catheter placement was developed by Ash at Lafayette, Indiana [92, 132, 133]. Tenckhoff and swan-neck Tenckhoff (straight and coiled) catheters may be implanted with this technique. Like blind insertion, it is performed through a single abdominal puncture. No fluid is instilled before insertion of the cannula and the trochar into the abdomen (through the medial or lateral border of the rectus). The trochar is removed, and the scope is inserted through the cannula. After assuring the intraperitoneal location by observing motion of glistening surfaces, the scope is removed and 600 cm^3 of air placed in the peritoneal cavity with the patient in the Trendelenburg position. The scope is reinserted and, during continuous observation, scope, Quill, and cannula are advanced into the clearest space and most open direction between the parietal and visceral peritoneum. Following this, the scope and

cannula are removed and the Quill catheter guide is left in place. The next step in the procedure involves the dilation of the Quill and musculature to approximately 0.5 cm. This is large enough to allow the catheter to be easily inserted through the rectus muscle and for the cuff to be advanced into the muscle. The catheter follows the path previously viewed by the peritoneoscope as directed by the Quill guide. As long as the Quill guide stays in position the catheter will advance into the desired place. The catheter is advanced on a stylet and is actually "dilating" its way until the cuff arrives and stops at the muscular layer. Placing the cuff in the musculature can be accomplished using a pair of hemostats advancing the cuff within the Quill guide. Thereafter, the Quill guide is removed, hydraulic function of the catheter checked, the tunnel made subcutaneously using a trochar, and the catheter brought out through the exit site – similar to the surgical insertion technique.

Excellent results with this technique were reported by its originator. Copley et al. [133] have reported their 1,183 patient-months experience with 135 double-cuff swan-neck coiled catheters inserted peritoneoscopically over a 40-month period. Complications were few and the overall 40-month survival probability was 62%. Nine catheters were removed because of obstruction and 16 for catheter-related infections.

Seldinger (Guidewire) and Peel-Away Sheath

This technique may be used for insertion of straight and coiled Tenckhoff catheters as well as of swan-neck Tenckhoff straight and coiled catheters. The preinsertion patient preparation is similar to the preparation described for rigid catheter insertion. The procedure may be done with [96] or without [93, 94, 134] prefilling the abdomen with dialysis solution. Prefilling of the abdomen is accomplished through a temporary peritoneal catheter.

In the "dry" method a 2-cm incision is made and the "dry" abdomen is entered with an 18-gauge needle (e.g., the Verres needle as used for laparoscopy). A guidewire is passed through the needle and the needle is withdrawn. The introducer (dilator) with sheath is passed over the guidewire. After the dilator-sheath is inserted, the dilator is removed, leaving the sheath in place. The Tenckhoff or swan-neck Tenckhoff catheter, stiffened by a partially inserted blunt stiffening stylet, is then directed down into the sheath [96]. The catheter may also be introduced without the stiff stylet [78, 134]. As the cuff advances, the sheath is split by pulling tabs on its opposing sides. Splitting the sheath allows the cuff to advance to a position within the abdominal wall. By further splitting and retraction, the sheath is removed from its position around the catheter. A subcutaneous tunnel is then created as in surgical placement. With this technique, the incidence of early leak is very low. However, the risk of viscus perforation and improper placement of catheter are the drawbacks of this technique.

Surgical (by Dissection)

Surgeons perform majority of catheter implantations; and 72% of catheter implantations are performed by surgical dissection [77]. Dissective placement is mandatory for catheters with stabilizing devices (e.g., flanges) at the parietal surfaces (Toronto Western Hospital, swan-neck Missouri abdominal, and swan-neck presternal). The paramedian approach through the rectus muscle, currently used in our center, will be described [84].

The surgical placement can be done either using a general anesthetic or using conscious sedation and local anesthesia. The decision depends on both surgeon and patient preference and somewhat on accepted local practice. Because of the long tunnel for the presternal catheter, our practice has been to use a general anesthetic to ensure patient comfort.

The surgical preparation of the abdominal wall consists of a scrub with Betadine soap, pat-drying, and painting with Betadine paint solution. Alternatively, DuraPrep, an iodine containing preparation, can also be used. It aids in adhering the sterile transparent surgical drape. In patients with iodine sensitivity, an alternative prep should be used. Skin markings are often very faint after surgical preparation and require remarking with a sterile surgical pen. Finally, the abdomen is covered with a sterile, iodine impregnated transparent surgical drape. The skin and surrounding tissues of the incision sites and tunnel are anesthetized with 1% lidocaine or 0.25% Marcaine (bupivicaine).

A 3–4 cm transverse incision is made through the skin and the subcutaneous tissue. Perfect hemostasis, preferably using electrocautery, is mandatory. The anterior rectus sheath is exposed and may be infiltrated with 1% lidocaine. A transverse incision is made in the anterior rectus sheath (Fig. 14.25). The rectus muscle fibers are separated bluntly in the direction of the fibers down to the posterior rectus sheath. Self-retaining retractors are helpful to hold muscle fibers away from the operative field. The sheath posterior rectus peritoneum may be infiltrated with 1% lidocaine. A 5-mm incision, reaching the peritoneal cavity, is made with a scalpel and stretched slightly (Fig. 14.26). The edges are grasped and elevated creating a pneumoperitoneum. A purse-string nonabsorbable suture of 2-O monofilament is then placed through in the posterior rectus sheath, transversalis fascia, and the peritoneum under direct vision.

The catheter is threaded on a long, blunt stiffening catheter guide. About 1 cm of catheter is left beyond the tip of the stylet to protect the intestine. The edges of the opening are lifted. The catheter is inserted through the opening and

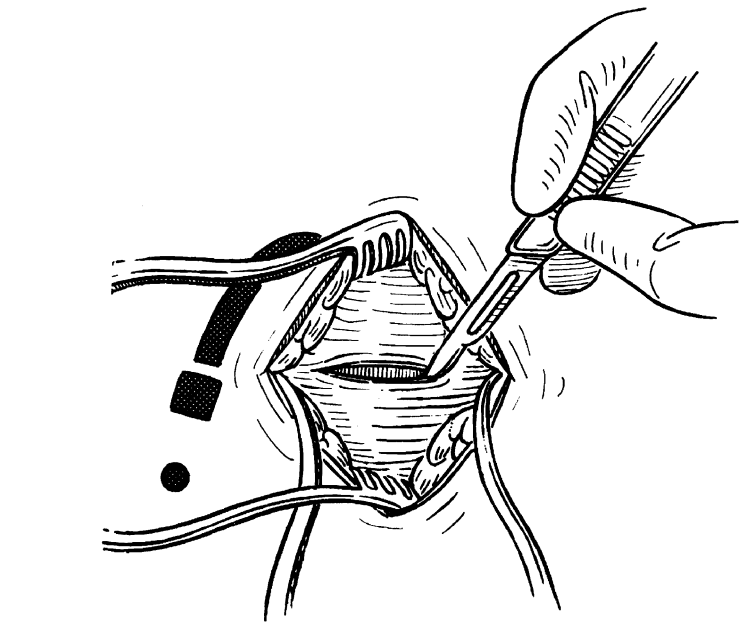

Fig. 14.25 An incision through the anterior rectus sheath

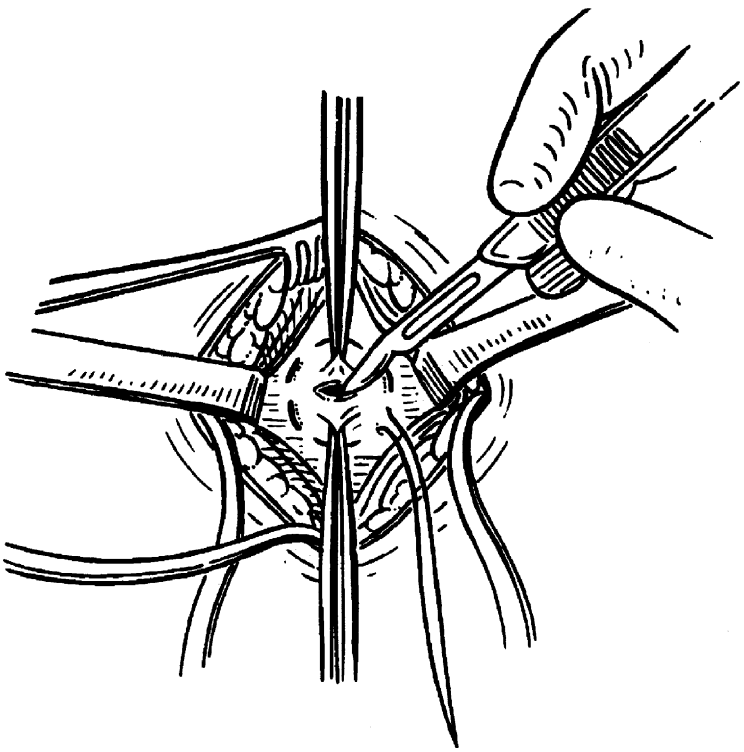

Fig. 14.26 The posterior rectus sheath has been exposed, a purse-string suture has been made, and a 5-mm incision reaching the peritoneal cavity is being created with a scalpel

introduced into the opposite deep pelvis if there is no resistance. If awake, the patient may feel some pressure on the bladder or rectum. When the catheter with catheter guide is about half to three-quarters inserted, the catheter guide is removed and the catheter continues to be directed into the pelvis.

Using a combination of retraction on the peritoneal edge and pushing, the bead is introduced into the peritoneal cavity. The flange is placed flat on the posterior rectus sheath and the purse-string suture is tied securely between the bead and the flange (Fig. 14.27). The stripe must be positioned anteriorly and the flange is anchored with at least two 2-O monofilament, nonabsorbable sutures into the posterior rectus sheath at the 6 and 12 o'clock positions (Fig. 14.28). The self-retaining retractors are removed and the deep or internal cuff is buried among the muscle fibers. A small stab wound is made in the anterior rectus sheath above the transverse incision. The catheter is grasped with a right-angled hemostat and pulled through the stab incision (Fig. 14.29). The stripe is positioned anteriorly. The

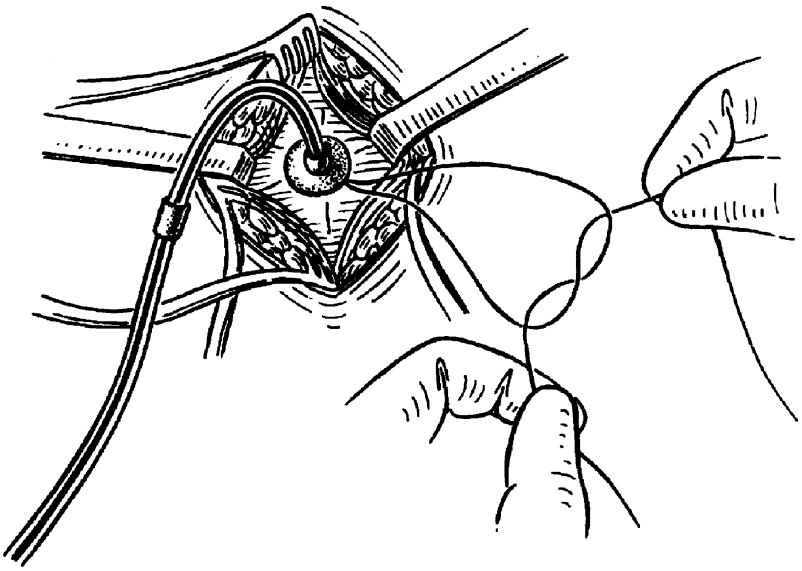

Fig. 14.27 A purse-string suture of peritoneum and rectus fascia is tied securely between the bead and the flange

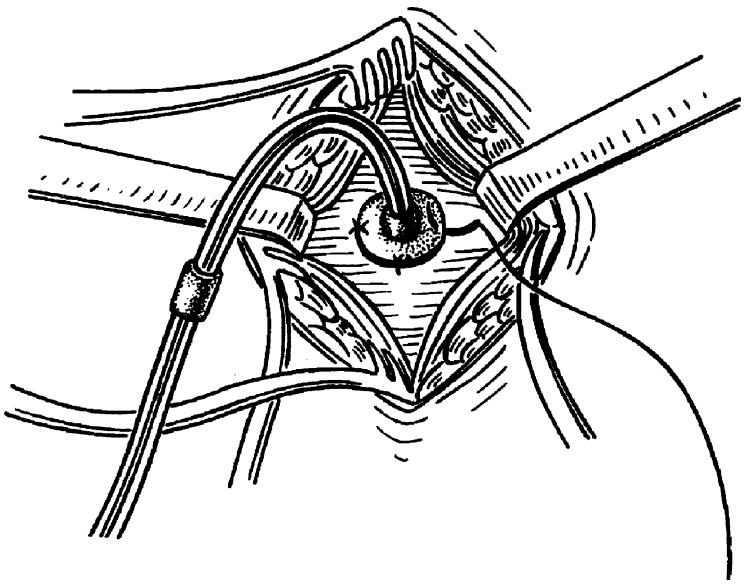

Fig. 14.28 The flange is anchored with four 2-O monofilament, nonabsorbable sutures into the posterior rectus sheath at the 6, 9, 12, and 3 o'clock positions

remaining procedure differs for the swan-neck abdominal Missouri and the swan-neck presternal catheter. The relationship of the catheter to the tissue structures of the abdominal wall is shown in Fig. 14.30.

Swan-Neck Abdominal Missouri

A superior subcutaneous pocket is made to the level of skin marking to accommodate the bent portion of the catheter and the external cuff (Fig. 14.31). The catheter tunnel extending from the cuff to the skin exit should have a diameter close to that of catheter tubing. Thus, the last portion of the tunnel (from external cuff to the exit) should be made with a piercing trochar, e.g., the Faller trochar (Covidien, Mansfield, MA 02048, USA) or a 3/16-inch (4.76 mm, F15) trochar for Hemovac system (Zimmer Mfg. Co., St. Louis, Missouri, USA) or the trochar for a 19 Blake drain (Ethicon, A Johnson & Johnson Company, Somerville, New Jersey) with an external diameter similar to that of the catheter tubing [84, 90, 97, 135]. A trochar is attached and carefully passed through the pocket and the external exit indicated by the stencil mark (Fig. 14.32). The bent portion of the catheter is positioned carefully in the subcutaneous pocket. Care is taken to keep the stripe facing frontward. The external cuff is positioned 2–3 cm from the skin exit. *No sutures are placed at the exit site to secure the catheter*. A titanium adapter is attached to the catheter and an extension tube is connected to the adapter [84]. A 1-L bag of sterile saline or dialysis solution containing 1,000 units of heparin is spiked via the extension tubing and the solution is infused. The fluid should all run in 5 min. The wound is checked for

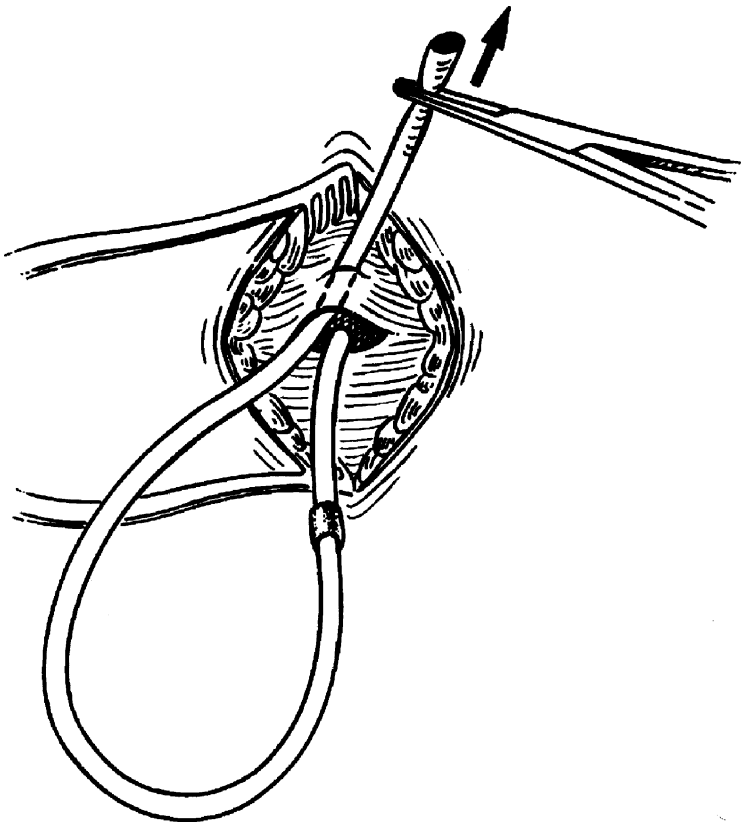

Fig. 14.29 The catheter is passed through the incision centered above the transverse incision

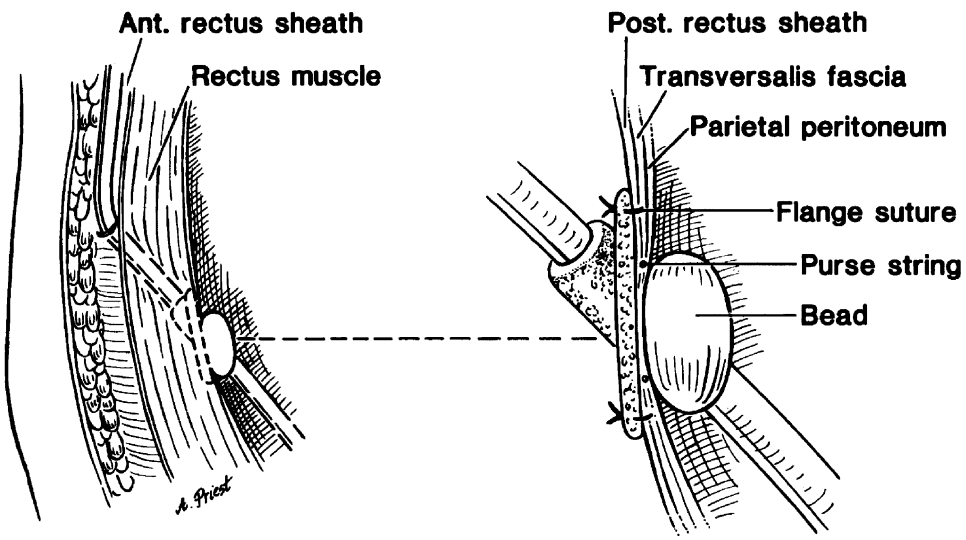

Fig. 14.30 The relationship of the catheter to the tissue structures of the abdominal wall. The bead is in the peritoneal cavity, the flange is flat on the posterior rectus sheath, the purse-string is between the bead and the flange, the deep cuff is in the rectus muscle

leaks and inspected for hemostasis. The transverse incision in the anterior rectus sheath is closed with a 2-O monofilament nonabsorbable suture. After infusing the dialysis fluid, the bag should be lowered to the floor and at least 200 mL of solution should drain within 1 min. If good flow is obtained the wound is irrigated and the skin incision is closed with absorbable subcutaneous and subcuticular sutures. The catheter is never sutured at the exit site. The position of the catheter is confirmed while still in the operating room on an abdominal X-ray. The incision is covered with Steri-strips, several layers of high-absorbency gauze dressings, and secured with Tegaderm®, which also immobilizes the catheter. The dressing is to be left in place for a week. In cases with bleeding, fever, or large drainage from the incision or exit the dressing should be changed earlier.

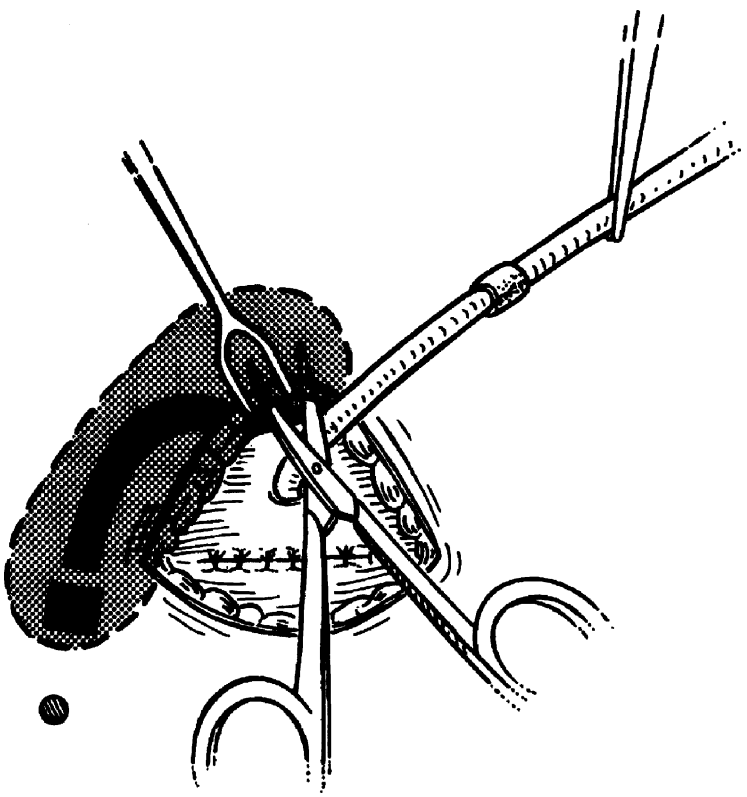

Fig. 14.31 A subcutaneous pocket is made to the level of skin marking to accommodate the bent portion of the catheter and the external cuff

Swan-Neck Presternal

A vertical 3–4 cm incision is made in the parasternal area (Fig. 14.33) at the level of the second and third rib at the stencil site [90]. Using a combination of sharp and blunt dissection, a superior subcutaneous pocket is made on both sides of the incision to accommodate the bent section of the upper (chest) tube of the catheter. The pocket is dissected enough to accommodate the middle and superficial cuffs (Fig. 14.34). Careful hemostasis is essential.

A Scanlan or Bard tunneler is used to create a tunnel extending from the abdominal incision to the presternal or parasternal area to permit joining the upper and lower tube. The tunneler, developed for tunneling vascular grafts, consists of an outside disposable or reusable sheath, blunt tip, and an inner rod with a handle at one end and a spring clamp or suture hole at the other. The metal rod serves to stiffen the tunneler as it is pushed through the subcutaneous tissue and the spring clamp or suture hole is used to secure the catheter and pull it through the sheath. Keeping the stripe in front as a guide, the abdominal end of the presternal portion of the catheter is pulled caudally through the sheath, and the sheath is removed by pulling in the caudal direction (Fig. 14.35).

The middle cuff of the upper catheter is carefully placed on the stencil mark. When the catheter is appropriately positioned the lengths of the two parts of the catheter are measured and the catheters are trimmed to an appropriate length. Sufficient length on each portion should be left to facilitate connection. A titanium connector is inserted into the presternal end and then the connector is inserted into the abdominal end of the catheter. The stripes on both tubes are positioned facing up. A 1-O Ethibond® tie is now placed and tied on both tubes over the appropriate groove of the titanium connector. The two sutures are tied together (Fig. 14.36) and the titanium connector is positioned in the subcutaneous tissue approximately 5–8 cm superior to the abdominal incision.

A trochar of the same size as the catheter tubing is attached and carefully passed through the pocket and the external exit site indicated by the stencil mark (Fig. 14.37). The stripe should be facing front. The trochar is disconnected. The bent portion of the catheter is carefully positioned in the subcutaneous pocket. The titanium Luer lock connector is attached. No sutures are placed at the exit site to secure the catheter. One liter of normal saline is infused through the infusion set and drained immediately. Outflow should be approximately 200 mL in 1 min. The wounds are checked for leaks, irrigated, and inspected for hemostasis. The transverse incision in the anterior rectus sheath is closed with a 2-O monofilament nonabsorbable suture. Skin incisions are again inspected for hemostasis. Any bleeding vessels are controlled with electrocautery and the incisions are closed with absorbable subcutaneous and subcuticular sutures. The operative site is covered with several layers of high-absorbency gauze dressings and secured with Tegaderm®, which also immobilizes the catheter. The dressing is to be left in place for a week.

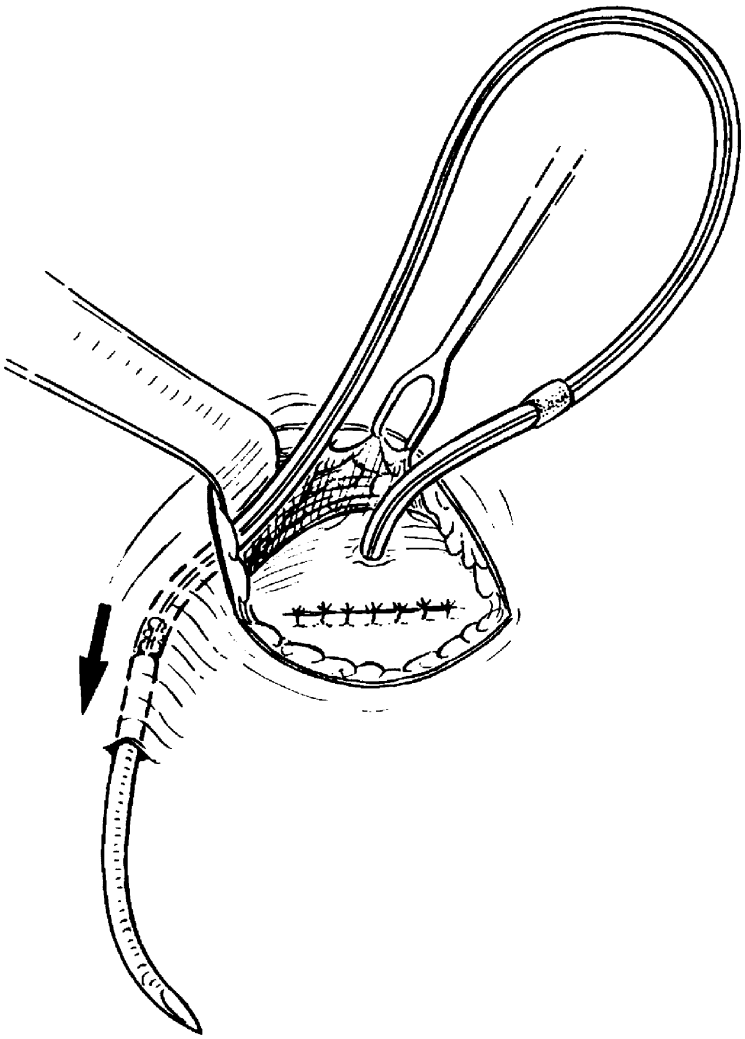

Fig. 14.32 A trochar is attached and passed through the pocket and the external exit indicated by the stencil mark. The piercing trochar is the same diameter as the tubing

Tenckhoff

This technique is similar to that of the swan-neck Missouri abdominal catheter; however, because there is no inter-cuff bend, the anterior stripe position is not essential and the subcutaneous pocket is not needed. Instead a straight upward or laterally curved tunnel is made with the help of a piercing trochar. The subcutaneous cuff is positioned 2–3 cm from the exit. As there is no flange, the deep cuff is positioned longitudinally, parallel to the rectus muscle fibers, on the posterior rectus fascia.

Swan-Neck Tenckhoff

A combination of techniques for the Tenckhoff and swan-neck Missouri abdominal catheters is used. The deep (inner cuff) is positioned longitudinally on the posterior rectus sheath with the stripe facing front. As explained earlier, in an earlier section entitled "Radiopaque Stripe," if the left catheter is used for the right tunnel and vice-versa, the stripe must be positioned posteriorly. The subcutaneous pocket is made in the same way as with swan-neck Missouri catheter.

Moncrief–Popovich Technique

This is an operative technique characterized by subcutaneous embedding of the external limb of the dialysis catheter at the time of implantation. The buried catheter is exteriorized after 3–5 weeks or when indicated to initiate dialysis [53]. This technique has been characterized as the "AV fistula of peritoneal dialysis" [136]. The advance placement of the catheter and the subcutaneous placement allow it to heal in a sterile environment. When exteriorized, patency is easily

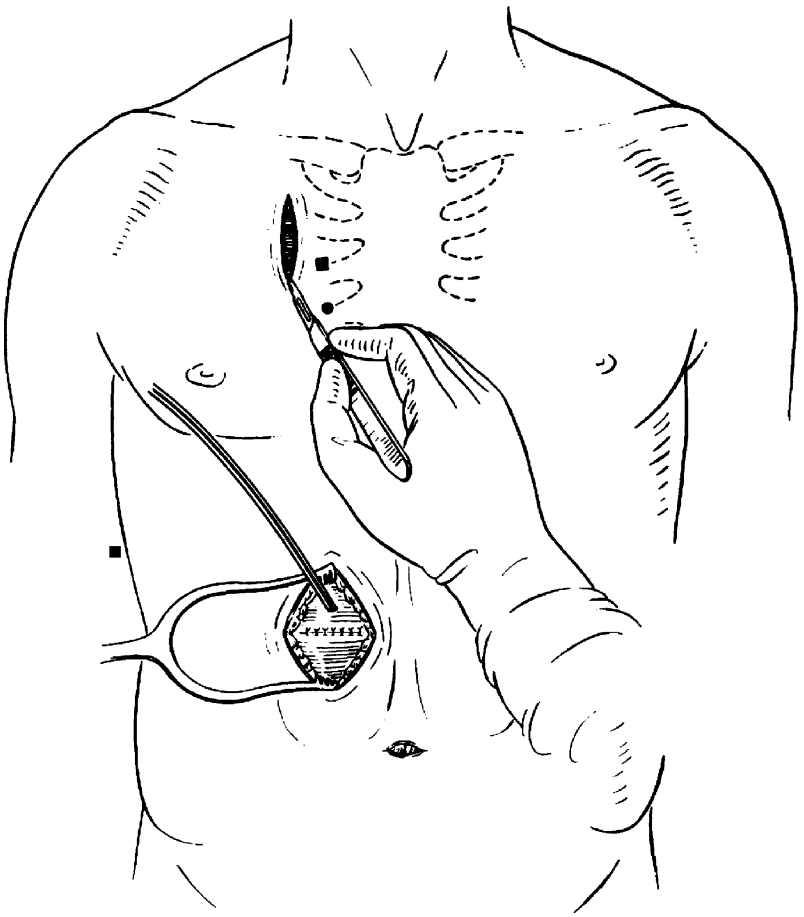

Fig. 14.33 Vertical incision in the parasternal area

established by irrigation or occasional use of a thrombolytic and only an occasional catheter needs surgical intervention [137]. Using swan-neck catheters with this technique, Moncrief and co-workers [53, 138] reported a significant reduction in pericatheter infections, exit-site infections and peritonitis but others have found no difference in peritonitis rate [139]. Some authors have noted an increase in perioperative complications such as seromas and subcutaneous hematomas [140]. A video [141] demonstrating the technique is available from the Austin Biomedical Research Institute, Austin, Texas, USA.

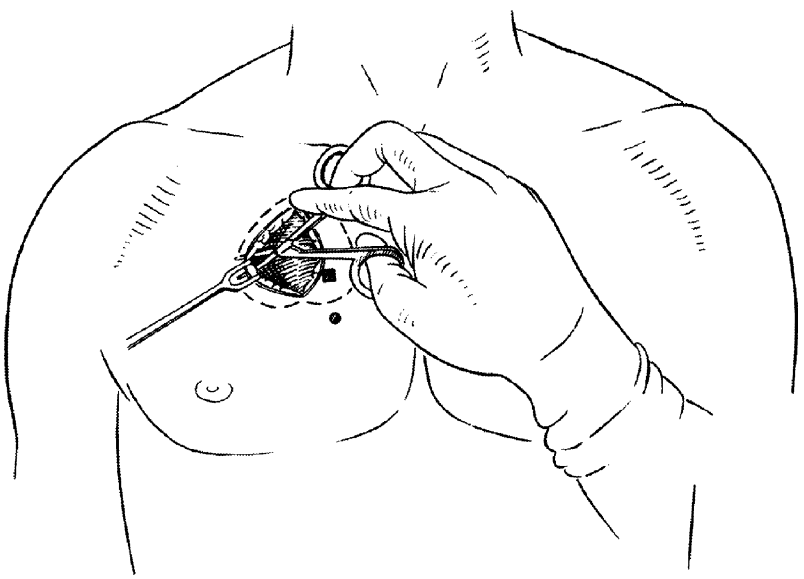

Fig. 14.34 Two small subcutaneous pockets are made on both sides of the chest incision to accommodate the bent section of the upper tube of the catheter

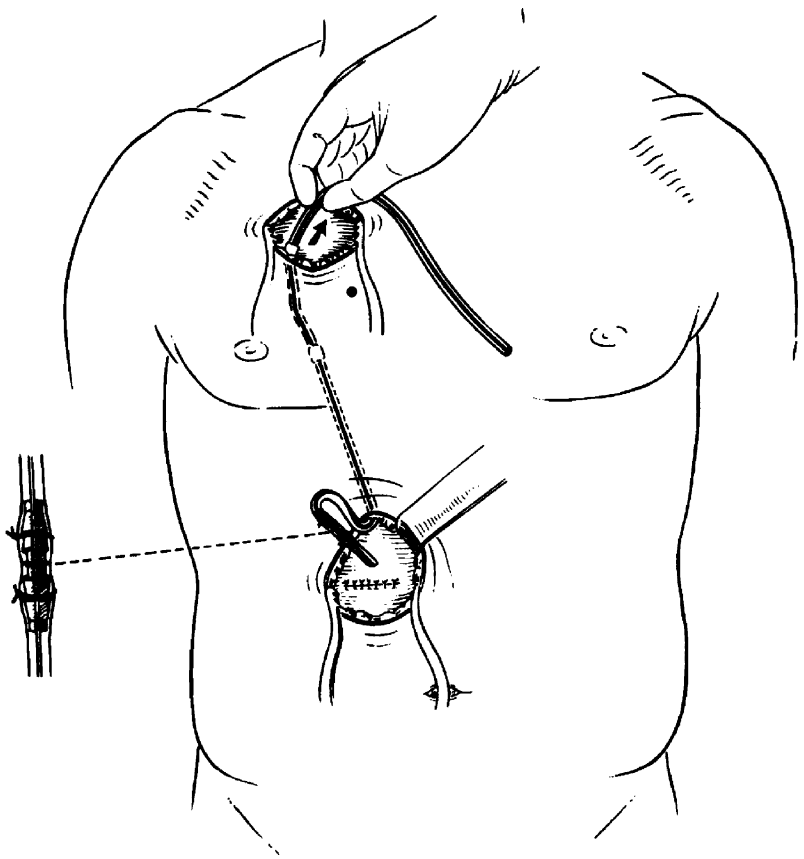

Fig. 14.35 A tunnel between the abdominal and chest incisions is made with a Scanlan tunneler, the upper tube is pulled caudally through the sheath

Laparoscopic Technique

Since the early 1990 s, there has been a significant change in the surgical approach to the abdomen. Starting in the early 1990 s laparoscopic approaches for all varieties of abdominal conditions began to replace traditional techniques. Naturally, these minimally invasive techniques were applied to placement of abdominal catheters. For almost two decades there has been a significant and increasing number of publications showing the efficacy and utility of using minimally invasive techniques for placing continuous ambulatory peritoneal dialysis catheters and managing their complications [142–153].

Nijhuis et al. [153] and Crabtree [154] have described a laparoscopic technique using a two-puncture technique for the placement of a continuous ambulatory peritoneal dialysis catheter. A pneumoperitoneum is created using a combination 4.5 mm trochar/Veress needle introduced into the contralateral upper abdominal quadrant. Crabtree and Fishman [154] use nitrous oxide to create a pneumoperitoneum allowing the procedure to be done under local anesthetic. A 3.5-mm zero-degree laparoscope is inserted through this trochar and an abdominal exploration is carried out. A 1.5–2 cm long incision is made in a perimedian site on the ipsilateral side of the abdomen. The subcutaneous tissues are dissected and the anterior rectus sheath is transversely incised. Using blunt dissection a pathway is created between and beneath the muscle. A 10-mm trochar is passed under visual control above the transversalis fascia and peritoneum. The trochar is then introduced into the abdominal cavity under direct vision and the peritoneal catheter is positioned in the pouch of Douglas. The cannula is removed and the catheter withdrawn so that the deep cuff is situated within the rectus muscle. The incisions are closed in standard fashion. This technique allows visual control and correct placement of the catheter in the pelvis. By placing the catheter in this fashion the authors have reduced their catheter-related problems and established a functioning catheter in about three-quarters of the cases.

The laparoscope can also be used for other purposes in patients on chronic peritoneal dialysis [155–159]. Specifically, catheter malposition and intra-abdominal adhesions are two conditions in which the laparoscope may be of considerable help. Entry to the abdominal cavity is established by direct cut down or Veress needle puncture in one of the upper abdominal quadrants. If an open technique is used, a purse-string suture is placed in the peritoneum and posterior fascia so that a snug fit around the trochar will be obtained. The trochar is inserted under direct vision with both techniques and a pneumoperitoneum is created by connecting to a CO_2 source. If the Veress needle approach is

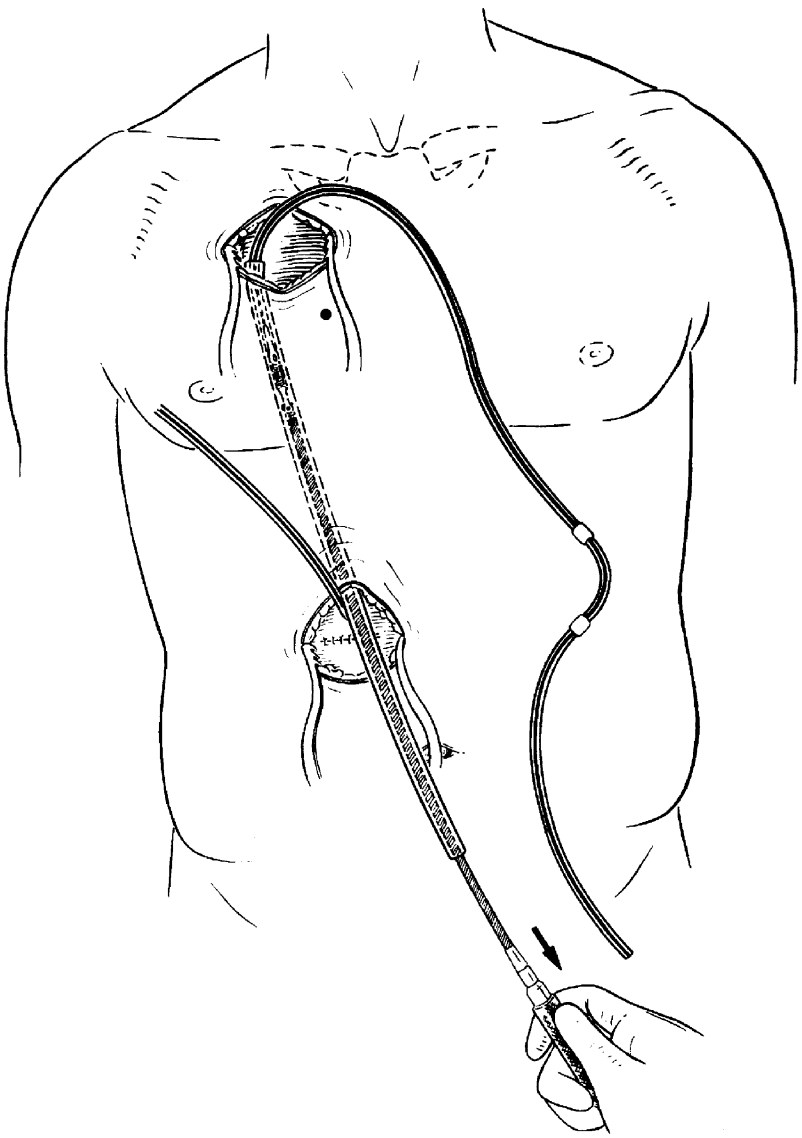

Fig. 14.36 Both parts of the catheter are tied over the titanium connector and the catheter is pulled cephalad

chosen, a pneumoperitoneum is first created then entry to the abdomen is made under direct vision using a Visiport Plus (Tyco Healthcare Norwalk, Connecticut, USA). Visual inspection will then demonstrate the problem of either adhesions and/or catheter malposition. Clinical judgment is used to place a second port, which is done under direct vision. Using grasping forceps or an electrocautery hook or scissors, the catheter can be repositioned, or the adhesions may be taken down. These techniques are of great help in salvaging an otherwise unworkable catheter.

Immediate and Early Postoperative Care

In the operating room, the position of the catheter is checked by a plain X-ray of the abdomen. Absence of catheter kink in the tunnel and the catheter-tip location in the true pelvis usually predict excellent catheter function. A liter of saline should be instilled in the peritoneal cavity and drained to confirm function prior to closing the incisions. Appropriate dressing of the exit site is placed in the operating room.

Postoperatively, we recommend performing exchanges until the dialysate return is clear. These may be done manually or using a cycler. One thousand units of heparin are added to each liter of dialysis solution. One-half or 1-L volumes of dialysis solutions are used for these exchanges. In spite of clear dialysate in the first postimplantation washout, the dialysate is usually blood-tinged in these exchanges. Once the dialysate returned is clear, the catheter is capped until peritoneal dialysis is initiated. There is no consensus whether a peritoneal washing should be performed

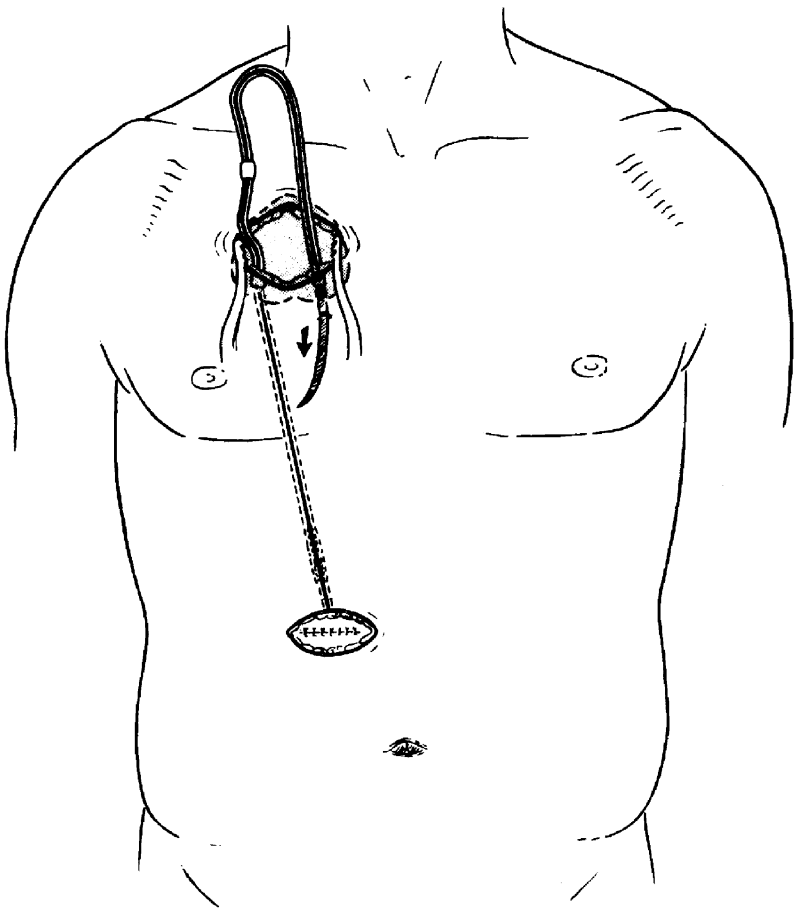

Fig. 14.37 A trochar of the same size as the catheter tubing is attached and carefully passed through the pocket, and the external exit is indicated by the stencil mark

once a week during the break-in period. The Moncrief technique of catheter implantation, leaving the external catheter buried until later exteriorization has not shown an increased rate of catheter obstruction.

Peritoneal dialysis should preferably be delayed for 2 weeks after implantation to allow for good healing and to prevent leaks [160]. If dialysis is required immediately, the options are to perform hemodialysis in the interim or to use low volume exchanges on peritoneal dialysis in the supine position. We do not commence peritoneal dialysis in the vertical position sooner than 14 days post implantation; thus, continuous ambulatory peritoneal dialysis (CAPD) or a last bag continuous cycling peritoneal dialysis (CCPD) are not used for 14 days.

Factors Influencing Catheter Complications

The common complications of peritoneal dialysis catheters include exit/tunnel infection; external cuff extrusion; obstruction, which is usually a sequel of catheter-tip migration out of the true pelvis with subsequent omental wrapping or tip entrapment in peritoneal adhesions; dialysate leaks; peritonitis; and infusion or pressure pain (Table 14.5). This section of the chapter will describe factors that influence these complications. A video illustrating these factors is available [97].

Table 14.5 Catheter-related common complications

Exit/tunnel infection	Pericatheter leak
External cuff extrusion	Peritonitis
Catheter obstruction	Infusion or pressure pain

Tissue Reaction to a Foreign Body Penetrating Skin

The tissue reaction begins immediately after a break in the integument occurs. Bleeding from capillaries and body fluids forms a coagulum of a hydrophilic fibrin–fibronectin gel and cellular debris. Various cytokines coordinate the subsequent entry of inflammatory cells and fibroblasts and the formation of new blood vessels [161]. Polymorphonuclear leukocytes phagocytose local bacteria and, together with the coagulum, form a scab. The polyester cuff also fills with clotted blood. Gradually, neutrophils, macrophages, fibroblasts, and new capillaries penetrate between the polyester fibers. Macrophages coalesce into giant cells and completely or partially surround the polyester fibers. Fibroblasts produce collagen fibers, which intertwine with the polyester fibers. The formation of the strong fibrous tissue is completed after approximately 6 weeks. Healing of the sinus starts beneath the scab with the production of granulation tissue composed of new vessels and fibroblasts. A mature granulation tissue is formed when neutrophils are replaced with mononuclear leukocytes, and fibroblasts lay down collagen fibers. Upon this tissue, there is a peripheral ingrowth of new epidermal cells.

Epidermal cells spread over the granulation tissue beneath the scab. Based on animal experiments it has been widely accepted that epithelial cells spread over granulation tissue until they meet epithelial cells from the opposite "shore" or until they encounter dense collagen fibers [162–171]. Winter [165] postulated that, in naturally occurring percutaneous organs such as teeth, the inhibition of epithelial migration is achieved by a periodontal membrane, which consists of bundles of collagen fibers embedded in the cementum of the tooth. In his view, other situations in which epidermal cell migration is inhibited include macroporous implants and skin autographs. Finally, he theorized that the basement membrane, a collagenous structure, also inhibits basal cell invasion of the dermis. The hypothesis that collagen fibers play a paramount role in inhibiting epithelial cell spreading led to the development of several devices of porous material to encourage dermal ingrowth and to prevent epithelialization of the tunnel ("marsupialization") [131, 167, 171, 172]. It has been suggested that the epithelium adjacent to a silicone catheter tends to migrate towards and beyond the subcutaneous cuff, creating a sinus between the tubing and the skin that is prone to bacterial colonization with subsequent infection [163].

The development of an epithelialized tract is well supported in animal models [60, 167, 170, 172] and in our previous reviews we cited these data as relevant in human peritoneal catheter sinus tracts [135, 173, 174]. However; our observations of catheter tunnels removed from patients showed that in almost all human peritoneal catheter tunnels the epithelium does not reach to the cuff, but stops a few millimeters from the exit in the sinus tract [175]. These observations lead us to believe that granulation tissue *per se* can also inhibit epidermal cell spreading. This observation also has an important influence on catheter design and implantation, particularly the material for the superficial cuff and its distance from the exit.

In humans, unlike experimental animals, the spreading of epidermis is slow. This discrepancy should not be surprising because the epidermal turnover rate in such animals is about six to seven times faster than in humans [176]. We found that in fast-healing catheter exits in humans the epidermis starts entering into the sinus after 2–3 weeks; in slow-healing exits the epidermis starts entering into the sinus after 4–6 weeks [69]. The healing process is complete after about 4–8 weeks, when the epidermis covers approximately half of a visible sinus tract with the remaining half covered with granulation tissue [69].

Tunnel Morphology after Healing Process Is Completed

A detailed description of peritoneal catheter tunnel morphology has been published elsewhere [175]. A well-healed tunnel of a double-cuff swan-neck Missouri catheter removed electively (Fig. 14.38) showed four segments: tissue ingrown to the flange and internal cuff, tissue surrounding the inter-cuff segment, tissue ingrown into the external cuff and the sinus tract. The most external part (0.5–1 cm) of the sinus tract and the skin surrounding the skin exit of the tunnel constitute the exit site. In the majority of humans the epidermal cells penetrate only a few millimeters from the skin exit and may reach the cuff located less than 15 mm from the exit [175, 177]. Although unusual, a single instance of keratinized epithelium penetration all the way to a cuff located 45 mm from the exit has been reported [178]. Close to the exit, the surface of the sinus tract is covered with wrinkled epidermis, containing all layers of epidermis including a horny layer. Deeper in the sinus, the epidermis loses the horny layer and becomes similar to the mucosal epithelium; hence the surface becomes glistening and white. The rest of the sinus tract is covered with the granulation tissue that is yellowish in appearance. A thick layer of collagen fibers surrounds the sinus. The granulation tissue contains numerous multinucleated giant cells, capillaries, cellular infiltrate composed mostly of mononuclear cells, and scant collagen fibers. The collagen fibers do not attach to the smooth surface of the silicone rubber, the material from which most peritoneal dialysis catheters are made.

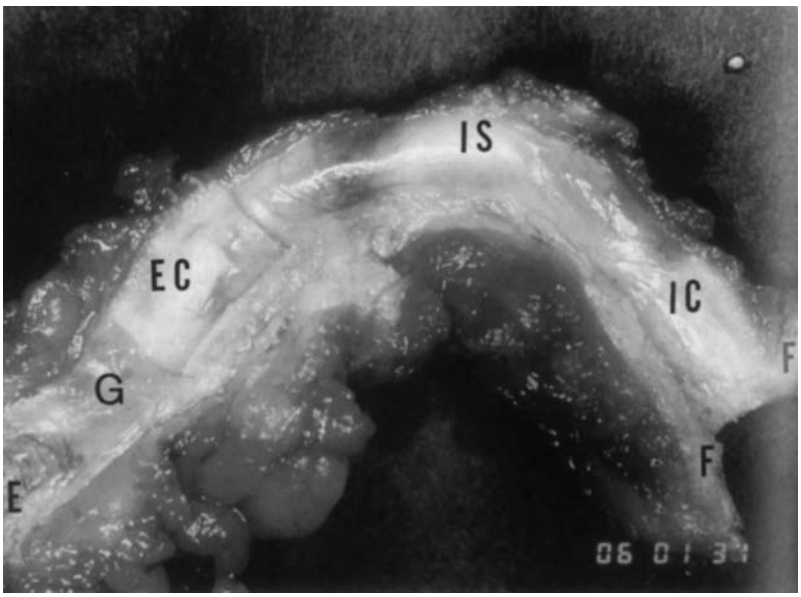

Fig. 14.38 A well-healed tunnel of a double-cuff swan neck Missouri catheter removed electively. From the left: E, epithelium; G, Granulation tissue; EC, external cuff; IS, intercuff segment; IC, internal cuff; F, flange

The junction between the granulation tissue in the sinus and the cuff is well defined. The cuff is surrounded by a dense fibrous capsule that contains numerous capillaries. About 80% of the polyester fibers are surrounded completely or partially by multinucleated giant cells. Spaces between the polyester fibers are filled with mature collagen and fibroblasts. No neutrophils are seen in an uninfected cuff.

The junction between the cuff and the inter-cuff segment shows a smooth surface without granulation tissue. The glistening, shiny inter-cuff tunnel segment resembles a tendon sheath and contains numerous micropits. The absence of any cellular reaction indicates that bacteria do not reach to this part of the tunnel. The surface is covered with an amorphous, mucinous substance on top of a modified layer of fibroblasts forming pseudo-synovium. There are no giant cells in this segment because silicone rubber *per se* does not induce giant cell formation.

The transition between the inter-cuff segment and the deep cuff is abrupt due to change from an avascular, acellular, fibrous sheath to a highly vascular and cellular tissue ingrown into the cuff. If the deep cuff is implanted into the muscle, the fibrous capsule surrounding the cuff and the cuff tissue itself are highly vascularized, otherwise the tissue ingrown into the cuff is similar to that of the external cuff.

Factors Influencing Healing and Early Infection

The most important factors influencing healing process and early infections are (Table 14.6) tissue perfusion, mechanical factors, sinus bacterial colonization, epithelialization, local cleansing agents, exit direction, and systemic factors.

Tissue Perfusion

The coagulum and necrotic tissue are gradually removed from the tunnel. Part of the necrotic tissue is absorbed and part is drained out of the tunnel. The tunnel should not be too tight with reference to the catheter circumference, so as to allow free drainage of necrotic tissue and to prevent tissue edema; both these factors decrease local perfusion and oxygen tension [179], which are critical for the wound-healing process. On the other hand, too large an incision prolongs healing by the shear volume of repair needed and the movement of loose tubing in the tunnel [180].

Table 14.6 Factors influencing healing process and infection

Tissue perfusion	Cleansing agents
Mechanical factors	Exit direction
Microorganisms	Systemic factors
Epithelialization	

Mechanical Factors

Mechanical stress slows the healing process [163]; thus the catheter should be relatively tightly anchored in the tunnel and also well immobilized outside the tunnel, especially during the break-in period [137]. Frequent dressing changes involve catheter manipulation, and hence should be avoided during the healing period. Constricting sutures at the exit site may cause pressure necrosis with skin sloughing, and facilitate bacterial penetration into the tissue; they must not be used [137].

Microorganisms

The presence of microorganisms in the wound is the major cause of impaired healing [181]. Bacterial counts exceeding 10^5 organisms per gram of tissue are associated with poor wound healing. Beta-hemolytic streptococci may affect healing regardless of the bacterial count in the wound [182]. Bacteria prolong inflammation and interfere with epithelialization, collagen deposition, and wound contraction [181]. Endotoxins produced by the bacteria stimulate release of collagenase, which contributes to collagen degradation and destruction of surrounding tissues [181]. Wound contamination by bacteria in association with hypoxia potentially suppresses macrophage-regulated fibroblast proliferation [183].

Maintaining sterility of the exit and sinus in the initial healing period is of utmost importance. Antibiotic penetration into the coagulum is poor; therefore, antibiotics should be present in sufficient concentration in blood and tissue fluids before the coagulum is formed. This may be achieved if antibiotics are given prior to implantation and is evidenced by several studies and a meta-analysis documenting preoperative intravenous prophylaxis reduce early peritonitis but not exit-site/tunnel infection [184].

Epithelialization

Epidermal cells grow over the granulation tissue beneath the scab. If the scab is forcibly removed during cleansing, the epidermal layer is broken, thus prolonging the process of epidermization. Sinus epithelialization is supported by sterile and undisturbed conditions at the exit. Again, frequent dressing changes facilitate exit contamination; on the other hand, liquid serous or sanguineous exudate at the exit promotes bacterial growth. Therefore, the exit should be kept dry, but dressing changes should not be too frequent.

Cleansing Agents

The objective of wound cleansing is to remove the organic and inorganic debris and to create conditions optimal for wound healing. Cleansing agents should not only decrease the number of bacteria, but also be harmless to the body defenses. Strong oxidants such as povidone-iodine and hydrogen peroxide are cytotoxic to mammalian cells [185, 186] and may impair angiogenesis [187]. It is prudent to apply such antiseptics only to the intact skin surrounding the wound or granulation tissue and avoid the sinus track [188]. Nonionic, amphophilic, nontoxic surfactants, widely used in burn wound care, facilitate necrotic tissue removal without jeopardizing body defense mechanisms [185, 189]. These include agents such as 20% Poloxamer 188 (Shur-Clens®; Calgon Vestal Laboratories, St. Louis, Missouri, USA) and Puriclens® (Care-Tech Laboratories, Inc, St. Louis, Missouri, USA), which are innocuous, yet excellent in cleansing the exit from contaminants.

Exit Direction

Exit direction is also important. Immediate postimplantation drainage of necrotic tissue is facilitated by gravity when the exit is directed downwards.

Systemic Factors

During the healing process, part of the granulation tissue is gradually resorbed and replaced by fibrous tissue. The fibrous tissue and part of the granulation tissue is covered with the epidermis [175]. Impaired nutrition, diabetes mellitus, uremia, hypothyroidism, obesity, chemotherapy, and corticosteroids are factors known to decrease wound healing by impeding the process of fibrosis [181]. It is prudent to avoid permanent catheter implantation while the patient is severely uremic, malnourished, or taking glucocorticoids.

Factors Influencing Infection of Healed Catheter Tunnel

Design of the catheter and its location in the created tunnel influences exit and/or tunnel infection. Other factors that may influence infection rate include bacterial colonization of the sinus, *S. aureus* nasal carriage status, catheter skin exit direction, sinus tract length, number off cuffs, and materials for the external cuff and the tubing in the sinus (Table 14.7).

Table 14.7 Factors influencing infection of healed catheter tunnel

Bacterial colonization of the sinus
Staphylococcus aureus nasal carriage
Catheter skin-exit direction
Sinus tract length
Number of cuffs
External cuff material and tubing in the sinus

Bacterial Colonization of the Sinus

Almost all healed catheter sinuses are colonized by bacteria [190]. It has been well documented in the surgical literature that wound infection is the result of imbalance between the host defense and bacteria [182]. The number of bacteria as a critical factor in wound infection was already recognized in World War I [191]. Elek [192] demonstrated that it requires 7.5×10^6 staphylococcal organisms to produce a pustule in normal human skin but the number of bacteria necessary to cause infection was reduced 10,000-fold in the presence of a single suture. Bacterial virulence is also important; *S. aureus* or *P. aeruginosa* are more likely to induce an inflammatory response than is *Staphylococcus epidermidis*.

It appears that there is a constant interaction between the colonizing bacteria and the body defense mechanisms at the sinus tract. The part of the sinus tract covered with epidermis seems to respond to bacteria in the same way as the rest of the body integument but the part covered with granulation tissue appears to respond by constant exudation of serum with white blood cells to suppress bacterial proliferation and curb their penetration deeper into the sinus. If the number of bacteria increase, then the amount of exudate increases and granulation tissue proliferates and becomes more vascularized. The number of bacteria entering deeper into the sinus depends on the number and species of bacteria at the exit site, exit direction, as well as sinus tract length, the latter an important contributing factor in the amplitude of catheter movement in the sinus. Optimum defense mechanisms, after the sinus is healed, are observed best in undamaged epidermis and granulation tissue; trauma to these structures may tilt the balance in favor of microorganisms and allow their rapid multiplication.

Nasal Carriage of S. *aureus*

The nose of patients on peritoneal dialysis is colonized by a variety of microorganisms including *S. aureus*, coagulase-negative *Staphylococcus*, and Gram-negative organisms [193]. While no association has been found between nasal colonization by coagulase-negative *Staphylococcus* and Gram-negative bacteria and peritoneal dialysis infections [193, 194], there is a strong association between *S. aureus* nasal carriage and catheter infections.

S. aureus principally resides in the anterior nares (vestibulum nasi or "nose picking area") [195]. There is strong correlation between the nasal and hand carriage of *S. aureus*. In the study by Boelaert et al. [196], 15 of 20 hemodialysis patients who carried *S. aureus* in their nares also carried the organism on their hands, but only two of 20 patients who did not carry *S. aureus* in their nares carried *S. aureus* on their hands ($p < 0.001$). Eighty-seven percent of patients who carried *S. aureus* in their nares and on their hands carried the same strain at both sites. Thus, it is likely that bacteria are carried from the nares to the vicinity of the catheter exit on hands.

Cross-sectional studies have established that approximately 50% of dialysis patients are nasal carriers of *S. aureus* [197, 198]. Nasal carriers are categorized into three groups based on longitudinal studies: persistent, intermittent, and noncarriage. Persistent carriers are usually colonized by a single strain of *S. aureus* over long durations of time, while intermittent carriers may carry different strains over time [195]. The load of *S. aureus* in the anterior nares of persistent carriers is higher resulting in increased dispersal and risk for infections [199]. In a study with median follow-up of 33 months, persistent nasal carriers had three times the number of peritoneal dialysis related infections than intermittent carriers and noncarriers, with majority of the isolated *S. aureus* being identical to the nasal isolates [200]. Luzar et al. [197] in a multicenter study reported on the increased incidence of exit-site infections in nasal carriers of *S. aureus*; in 85% of these infections the strain from the nares and the strain causing the infection were similar in phage type and antibiotic profile. The risks of staphylococcal catheter-related infections are higher in nasal carriers with diabetes mellitus or those who are immunosuppressed [201].

A few studies have failed to find an association between *Staphylococcus* carriage and *Staphylococcus* catheter-related infections [202, 203]; however, the overwhelming evidence does support this association. Furthermore, several studies have documented the benefits of treating the nasal colonization of *S. aureus* [204–208] and are discussed in a subsequent section of this chapter.

Catheter Skin-Exit Direction

The original recommendation of a downward-pointing exit came from Tenckhoff and Schechter [34]. A retrospective analysis from the University of Missouri found that compared to upward-directed exits, the exits directed downwards tended to be infected less frequently and, once infected, were significantly less resistant to treatment [50]. Several other authors have demonstrated superiority of downward directed exit sites in both pediatric and adult populations [209–211]. This should not be surprising since upward-directed tunnels facilitate exit contamination by gravity-aided flow of sweat, water, and dirt (Fig. 14.39). Once the exit is infected, it is resistant to treatment because of poor external drainage; rather, the pus tends to penetrate deeper into the tunnel. In addition, downward drainage of necrotic tissue immediately postimplantation is easier than drainage against gravity.

The advantage of caudal exit direction in preventing and treating infections has support in several other clinical conditions. Periodontitis, which may be considered as a naturally occurring "foreign" body exit-site infection, most frequently effects the lower incisors ("exits" directed upwards) [212]. The influence of exit position on the frequency and tenacity of paranasal sinus infections was postulated by Zuckerkandl in the nineteenth century. The relatively frequent infections of the maxillary sinus are believed to be due to unfavorable positions for discharge because the *ostium maxillare* (in the upright position of the body) is located at the highest point of the cavity; the cavity must be completely filled with secretions before the discharge may escape [213]. All of the other cavities are more favorably constructed for drainage and less likely to be infected [213]. The use of downward directed tunnels have been demonstrated to be effective in reducing exit-site infections in chemotherapy catheters and pediatric hemodialysis tunnels [214, 215].

Lateral pointing exit sites may be necessary in some individuals due to body habitus. In a retrospective study, downward and lateral catheter tunnel-track and exit site produced equivalent outcomes for infectious and mechanical complications [216].

Swan-Neck Catheters

Based on the observations that downward-exiting catheters are less likely do develop infections, Twardowski et al. developed the permanently bent swan-neck catheter with an inverted U-shaped arc between the deep and superficial cuffs. The U-shaped, arcuate bend allows the catheter to exit the skin pointing downward and the intraperitoneal segment is also directed downward to the pelvis [50]. The preformed shape promotes pelvic orientation by eliminating

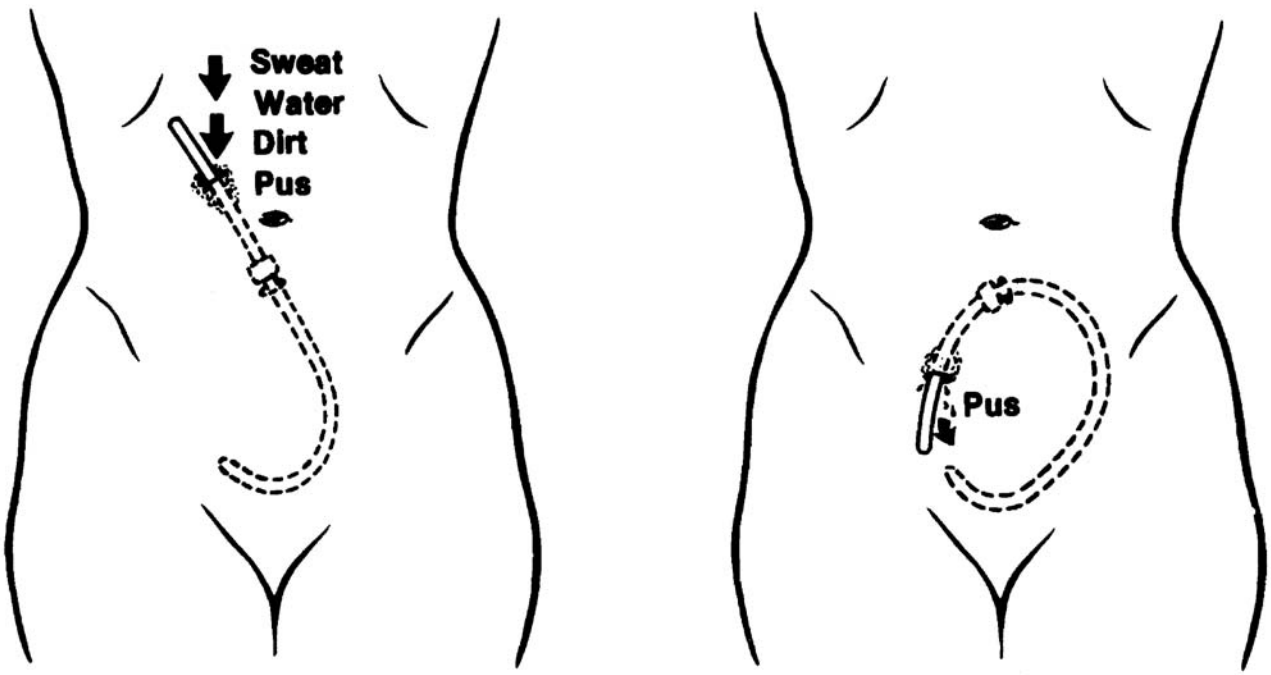

Fig. 14.39 *Left*: exit easily contaminated with down-flowing sweat, water, and dirt; difficult pus drainage prolongs treatment. *Right*: good pus drainage facilitates recovery. Reproduced from [50] with permission

shape memory effects. The surgical insertion of swan-neck catheters requires greater planning and technical skill for creating an appropriate tunnel than a straight catheter [1]. The data from Twardowski et al. [83], Lye et al. [217], and others has shown reduced exit-site infections with swan-neck catheters while others such as Hwang and Huang [218] and Eklund et al. [219, 220] demonstrated no benefit in the incidence of exit-site infections. These swan-neck catheters offer benefits in a lower incidence of cuff migration [79] and less frequent drainage related issues [79, 217, 220, 221].

Sinus Tract Length

The epidermis covering the sinus tract undergoes a turnover probably similar to the normal epidermis with cell maturation and desquamation; granulation tissue produces exudate. All these contents, if not expelled, create a favorable milieu for bacterial growth. With a long sinus tract the chances of infection are higher [162–164]; therefore, the sinus tract should be as short as possible. Tenckhoff recommended that "the subcutaneous Dacron®; felt cuff should be located immediately beneath the skin exit" [89]. Such a localization of the cuff, however, predisposes to its extrusion. Indeed, in some centers the rate of extrusion reached 100% [222]. In other centers the rate, although lower, was high enough to question the wisdom of using the superficial cuff at all. The most recent recommendation is to place the subcutaneous cuff at least 2–3 cm from the exit site [223].

Number and Location of Cuffs

There are three basic shapes and designs for the Dacron® cuffs: a single cuff around the catheter, usually placed in the rectus muscle but sometimes on the outer surface of the rectus; dual cuffs around the catheter, one in the rectus sheath and the other in the subcutaneous tissue; and a disc-and-ball deep cuff, with the parietal peritoneum sewn between the Dacron® disc and the silicone ball (Toronto-Western and Missouri catheters) [224]. The presternal catheters have three Dacron® cuffs: The upper tube carries two cuffs, a superficial and a middle or central spaced 5 cm apart, and a single deep cuff incorporated on the abdominal tube.

Single external-cuff catheters were used by Tenckhoff for treatment of acute renal failure. This type of catheter used in patients undergoing chronic intermittent peritoneal dialysis yielded similar results to those of the double-cuff catheter; however, with continuous ambulatory peritoneal dialysis, double-cuff catheter survival was better than of these catheters [225]. The complications of catheters with a solitary external cuff include the development of pseudohernias due to high intra-abdominal pressure from the constant presence of fluid in the peritoneal cavity. The use of such catheters has been abandoned.

Another type of single-cuff catheter has only a deep cuff. This type of catheter has been used because of problems with external-cuff extrusion and the questionable value of the external cuff. Earlier studies found such single-cuff catheters to be associated with a shorter time to first peritonitis episode and shorter survival times than the double-cuff catheters [211, 226–229]. However, the matter is not settled as a randomized controlled trial of 60 patients compared single- versus double-cuff catheters and found no differences in peritonitis, exit-site infections, and catheter survival [230].

Material for the External Cuff and Tubing in the Sinus

Peritoneal dialysis catheters are manufactured using highly biocompatible polymers, which minimize the foreign body reaction and enhancing device longevity. A thin fibrous capsule usually develops around the catheter but does not adhere to the catheter. Consequently, a potential space exists between the catheter and the fibrous layer that allows movement of the catheter and permits infection to spread from the exit site to the peritoneal cavity. Fabric cuffs are used to provide anchorage to the catheter [231]. The external cuff, if used, may play a role in preventing the spread of epidermal cells into the sinus track. As an example of perfect arrangement the anatomy of the tooth/gingival interface is cited [171]. The periodontal ligament attaches to the cementum, creating an extremely strong bond. The cementum is composed of hydroxyapatite crystals, collagen fibers, proteoglycans, and mucopolysaccharides [232]. Such a living material is unlikely to be used for the external cuff.

The traditional cuffs are made of polyester fiber (Dacron®). Soon after implantation, there is an acute inflammatory reaction characterized by the accumulation of polymorphonuclear cells and activated macrophages and eventually develop into foreign body giant cells. Later, fibroblasts and blood vessels grow into the cuff. In mature uninfected cuffs, histopathology reveals giant multinucleated cells, sparse mononuclear cells, and collagen fibers intertwined with the polyester fibers. A fibrous capsule surrounds the cuff. The tissue ingrown into the cuff *per se*

does not seem to constitute a critical barrier for infection spreading [175]. It seems that the basic beneficial role of the external cuff in infection prevention is by anchoring of the catheter resulting in restriction of its piston-like movements, thus decreasing transport of bacteria into the sinus. Favorable results with a "wing" instead of cuff appear to give clinical support to this hypothesis [233]. This "wing," however, does not seem to anchor the catheter as well as the cuff. Cuffs made of titanium fiber mesh have been evaluated in animal models and appear more biocompatible and integrate more favorably in the surrounding tissue [234].

Bioactive coating of catheters may be an alternative to cuffs. In animal studies, a bioactive glass-ceramic coating of silicone catheters was successful in inducing tissue adhesion of silicon catheters by promoting adhesion and cell proliferation [231]. In another animal study, a biocompatible silicone material with micropores was used as a cuff. The micropores facilitated ingrowth of blood vessels and loose collagen and cellular matrix, improving biointegration and decreasing exit-site infections. However, further studies and human data are needed to accept a substitute for polyester fabric (Dacron® velour) as a material for the external cuff.

In animal studies, it has been demonstrated that polyurethane intravenous catheters are less prone to infections than silastic intravenous catheters [235]. This may be related to differences in surface irregularities effecting microbial adherence. No studies have addressed differences in exit-site infection between polyurethane and silicon rubber peritoneal dialysis catheters in a direct comparative study. The incidence of exit-site infections with the Cruz dialysis catheter, which is made from polyurethane, are no different than reported in literature for silicone catheters [236, 237]. However polyurethane catheters are less biostable and the Dacron® cuff is more likely to separate from the catheter [238].

Exit Sites: Classification and Care

Exit-Site Appearance Post Implantation

Unless a large hematoma in the wound is present, all exits look the same a week after implantation [69]. The exit is painless or minimally tender with light pink color of less than 13 mm in diameter from border to border (including the width of the catheter). Blood clot or serosanguineous drainage is visible in the sinus. No epidermis is visible in the sinus and the sinus lining is white and plain. Signs of good healing include a decrease in color saturation and diameter around the exit, change of drainage to serous, decreased drainage amount, decreased tenderness, and progression of epidermis into the sinus. An increase in color, diameter, or saturation around the exit; change of drainage to yellow; change of granulation tissue color to mottled, pink or red; or change of granulation tissue texture into slightly exuberant or exuberant are signs of poor healing.

Our exit-site study [69, 239] revealed four types of healing exits: 1) Fast-healing exits had no drainage or minimal moisture deep inside by the third week; epidermis started to enter into the sinus within 2–3 weeks, progressed steadily, and covered at least half the visible sinus tract 4–6 weeks after implantation. 2) In slow-healing exits without infection, epidermis started to enter into the sinus after 3 weeks or progressed slowly and did not cover half the visible sinus by 5 weeks; the sinus might have had serous or serosanguineous, but never purulent, drainage persistent up to 4 weeks. 3) Healing interrupted by infection initially looked identical to the fast-healing exit, but within 6 weeks the epidermis had not progressed, or had regressed, granulation tissue became soft or frankly fleshy; drainage increased and/or became purulent. 4) In slow-healing exits due to early infection, granulation tissue became soft or fleshy and/or drainage became purulent by 2–3 weeks; sinus epidermization was delayed or progressed slowly, only after infection was appropriately treated.

Classification of Exit-Site Appearance

Attempts to classify exit appearance into two categories (infected and not infected) are difficult, if not impossible, because infected and uninfected exit appearances overlap. This overlap is due to the peculiarity of tissue reaction to the foreign body penetrating the skin, and stems from the delicate balance between bacteria in the sinus and host defenses as described above. The presence of a small amount of exudate causing crust formation does not indicate infection, but if the bacterial attack is more severe, or the host defenses are weakened, then the amount of exudate increases; granulation tissue proliferates, becomes more vascularized, epithelium regresses, and signs of infection become obvious. Low-grade exit infection may abate without systemic antibiotics.

We have performed extensive evaluation of exit-site characteristics [69, 190]. From the 565 evaluations of 61 healed exit-sites in 56 patients evolved a new classification [240]. The classification is based on the cardinal signs of inflammation as proposed by Aulus Cornelius Celsus in his treatise, *De Medicina*, written in the first century AD. These are well known: *calor* (heat), *rubor* (redness), *turgor* (swelling), and *dolor* (pain). Additional features, specific for an exit of any skin-penetrating foreign body, are drainage, regression of epidermis, and exuberance (profuse overgrowth) of granulation tissue ("proud flesh"). Granulation tissue is defined as exuberant if it is significantly elevated above the epidermis level. Scabs and crust do not indicate infection. Culture results did not influence exit classification. Positive cultures in exits not inflamed indicate colonization, not infection. Cultures were commonly negative from infected exits on antibiotic therapy. However, inflammation in almost all cases is caused by infection, regardless of culture results. Inflammatory responses to tubing itself or local irritants are rare.

Improvement or deterioration of inflammation is associated with respective decreases or increases of pain, induration, drainage, and/or exuberant granulation tissue, and/or regression or progression of epithelium in the sinus. Increased lightness (pink, pale pink) or darkness (deep black, brown) and decrease in color diameter indicate improvement, increase in red color saturation and diameter indicate deterioration. Ultimately, a new classification with five distinct categories of exit appearances has been established: acute infection, chronic infection, equivocal, good, and perfect. Two special categories are included: external cuff infection and traumatized exit. Trauma may result in various appearances. Cuff infection may not be associated with exit infection. Detailed descriptions of the various exit appearances illustrated by over 200 color photographs have already been published [69, 190, 239–241]. The characteristics for each category of catheter exit site are summarized in Table 14.8.

Acute Catheter Exit-Site Infection

This involves purulent and/or bloody drainage from the exit-site, spontaneous or after pressure on the sinus, and/or swelling; and/or erythema with diameter 13 mm or more from border to border; and regression of epithelium in the sinus. Acute catheter inflammation lasts less than 4 weeks and may be accompanied by pain, exuberant granulation tissue around the exit or in the sinus, and the presence of a scab or crust.

The common pathogens are *S. aureus* and *P. aeruginosa* [242–245]. Other organisms causing exit-site infection are coagulase-negative *Staphylococcus*, diphtheroids, anaerobes, streptococci, legionella, and fungi. Exit-site culture may be negative in patients receiving antibiotics.

Chronic Catheter Exit-Site Infection

These are characterized by purulent and/or bloody drainage from the exit-site, spontaneous or after pressure on the sinus; and/or exuberant granulation tissue around the exit and/or in the sinus; and regression of epithelium in the sinus. Chronic infection persists for more than 4 weeks and crust or scab is frequently present. Swelling, erythema, and/or pain indicate exacerbation. Exit culture may be negative in patients receiving antibiotics.

Equivocally Infected Catheter Exit Site

There is purulent and/or bloody drainage, which cannot be expressed outside the sinus, accompanied by the regression of epithelium, and occurrence of slightly exuberant granulation tissue around the exit and/or in the sinus. Erythema with a diameter less than 13 mm from border to border may be present, but pain, swelling, and external drainage are absent. Exit culture may be negative in patients receiving antibiotics.

Good Catheter Exit

Exit color is natural, pale pink, purplish, or dark and there is no purulent or bloody drainage. Clear or thick exudate may be visible in the sinus. Mature epithelium covers only part of the sinus; the rest is covered by fragile epithelium or plain granulation tissue. Pain, swelling, and erythema are absent. Positive peri-exit smear culture, if present, indicates colonization not infection.

Perfect Catheter Exit

This is at least 6 months old with its entire visible length of sinus tract covered with the keratinized (mature) epithelium. Exit color is natural or dark and there is no drainage. A small, easily detachable crust may be present in the sinus or around the exit. Positive peri-exit smear culture, if present, indicates colonization not infection.

Table 14.8 Characteristics of each category of exit-site appearance

	Perfect	Good	Equivocal	Acute infection <4 weeks	Chronic infection >4 weeks	Cuff infection without exit infection
Exit						
Pain/ tenderness	None	None	None	May be present	Only if exacerbation	May be present over cuff
Colour	Natural, pale pink or dark	Natural, pale pink, purplish or dark, bright pink <13 mm	Bright pink or red <13 mm	Bright pink or red >13 mm	Bright pink or red >13 mm only if exacerbation	Natural, pale pink, purplish or dark, bright pink <13 mm
Crust	None or small, easily detached or specks of crust on dressing	None or small, easily detached or specks of crust on dressing	Present, may be large and difficult to detach	Present	Present, may be difficult to detach	Typically absent
Scab	None	None	None	May be present	May be present	Absent
Drainage	None	None	None even with pressure on sinus; dried exudate on dressing	Purulent or bloody, spontaneous or after pressure on sinus; wet exudate on dressing	Purulent or bloody, wet exudate on dressing	Chronic or intermittent; purulent, bloody, tenacious or "gluey"
Swelling	None	None	None	May be present	Occurs only if exacerbation	Cuff induration may be felt on palpation; negative ultrasound does not rule out the diagnosis
Granulation tissue	None	None	Plain or slightly exuberant	Slightly exuberant or "proud flesh" may be present	"Proud flesh" or slightly exuberant typically visible	None
Sinus						
Epithelium	Strong, mature; covers visible sinus	Strong, mature at rim; fragile or mucosal deeper	Absent or covers part of sinus	Absent or covers part of sinus	Absent or covers only part of sinus	Covers most or all of sinus; may be macerated
Granulation tissue	None	Plain beyond epithelium	Slightly exuberant	Slightly exuberant or "proud flesh"	"Proud flesh" or slightly exuberant	None or exuberant deep in sinus
Drainage	None or barely visible; clear or thick	None or barely visible clear or thick	Purulent or bloody, sometimes clear	Purulent or bloody	Purulent or bloody	Purulent, bloody, gluey; may be seen only after pressure on cuff; clot or dried blood in sinus

Trauma may result in pain, bleeding, scab, and deterioration of exit appearance. Exit appearance depends on intensity of trauma and time of evaluation. Reprinted from [241] with permission

External Cuff Infection Without Exit Infection

There is intermittent or chronic, purulent, bloody, or gooey drainage, spontaneous or after pressure on the cuff, and induration of the tissue around the cuff. Exuberant granulation tissue may be seen deep in the sinus; sinus epithelium may be macerated. Exit site may look normal on external examination. Ultrasound may show fluid collection around the cuff, but negative ultrasound does not rule out cuff infection. Exit culture may be negative in patients receiving antibiotics.

Traumatized Exit

Features of traumatized exit depend on the intensity of trauma and the time interval until examination. Common features of trauma are pain, bleeding, scab, and deterioration of exit appearance (e.g., perfect exit transforms to good or equivocal or acutely infected).

Alternative Exit-Site Classification Systems

Several alternative classification of exit sites have been proposed [246–248]. The scoring system by Schaefer et al. [246] is based on an Exit-Site Score (ESS, 0–10). The parameters include the presence of an erythema (0, none; 1, <0.5 cm; 2, >0.5 cm), a crust (0, none; 1, <0.5 cm; 2, >0.5 cm), tenderness (0, none; 1, moderate; 2, severe), swelling (0, none; 1, moderate; 2, severe), and discharge (0, none; 1, clear; 2, purulent). The exit site is considered infected if the total score exceeds 4 or greater. Purulent drainage alone is sufficient to indicate infection [246] . This system has been validated only in children.

Exit-Site Care

Early Care

Early colonization of the exit was the most significant factor in determining the healing pattern; the later the colonization, the better healing [69]. Positive culture from either sinus washout or peri-exit smear 1 week after implantation was associated with early exit infection, a higher peritonitis rate, and a high probability of catheter loss due to an exit/tunnel infection, and higher peritonitis rate; however, the time to the first peritonitis episode was not shorter than in the groups with later exit colonization [69].

The goal of early care is to delay bacterial colonization and to minimize trauma to the exit site. After implantation, the exit site should be covered with sterile gauze and occlusive dressings must be avoided. Gauze dressings can wick away drainage from the exit and keep the exit site dry. It is generally agreed that postoperative dressing changes should be restricted to specially trained staff [249]. Dressings should not be changed frequently unless there is evidence of bleeding or significant drainage [250]. Our usual practice is to change dressings every week for the first 2 weeks. Once the exit is colonized, by week 3 in the majority of cases [69], more frequent dressing changes are indicated, because the major rationale for infrequent dressing changes, avoidance of exit colonization, no longer exists. Moreover, more frequent cleansing of the exit will decrease the number of bacteria at the exit. Aseptic technique, including both masking and wearing sterile gloves, should be used for postoperative dressing changes. Nonionic surfactant such as 20% poloxamer 188 (Shur-Clens®) is used to help gauze removal if it is attached to the scab. If the scab is forcibly removed, the epidermal layer is broken, a new scab has to be made, and the epidermization is prolonged. Care is taken to avoid catheter pulling or twisting. The exit sites may be cleaned with normal saline, nonionic surfactant, hydrogen peroxide, or povidone-iodine. Povidone-iodine and hydrogen peroxide are cytotoxic and should be kept out of the exit-site sinus. After cleansing, the exit site should be patted dry with sterile gauze, covered with several layers of gauze dressings, and secured with air-permeable tape.

The exit and visible sinus should be evaluated for quality of healing at each dressing change throughout the 6-week healing period. If healing does not progress, if there are signs of deterioration or infection, the exit is probably already colonized [69]. A clinical culture of the exudate should be taken, and an appropriate systemic antibiotic should be given.

It is recommended that patients do not shower or take tub baths post-catheter implantation, to avoid colonization with waterborne organisms, and to prevent skin maceration. Once more frequent dressing changes are started (after approximately 2 weeks), the patient may take a shower, but only before the dressing change, otherwise he/she must take sponge baths and avoid exit wetting.

Protecting the catheter from mechanical stress is extremely important, especially during break-in. Catheters should be anchored in such a way that the patient's movements are only minimally transmitted to the exit. Although a variety of devices are available to immobilize the dialysis catheter, these devices have not been shown to be any more effective than tape and dressings in preventing infections [251]. The method of catheter immobilization should be individualized, depending on exit location and shape of the abdomen.

Chronic Exit-Site Care

Local Care

The components of chronic exit-site care include assessment and cleansing of the exit-site, immobilization of the catheter and protection of the exit site from trauma. Chronic exit-site care is the responsibility of the patient or the caregiver along with close attention by the physician and nurses on office visits.

Frequent, preferably daily, exit site care is optimal. Cleansing of the exit site is essential to reduce resident bacteria. The exit site is first washed with antibacterial soap and water or with a nonionic surfactant such as 20% poloxamer 188 (Shur-Clens®). Povidone-iodine, chlorhexidine, and Amuchina may be used as disinfectants in routine exit-site care. These agents should not be allowed into the exit-site sinus. After cleansing, the exit has to be patted dry with sterile gauze.

The results of a prospective study by our group indicate that cleaning with soap and water is the least expensive and tends to prevent infections better than povidone-iodine painting and hydrogen peroxide cleaning [252]. Others have found povidone-iodine to be superior to nondisinfectant soap [253].

Amuchina is an electrolytic chloroxidizing solution containing sodium hypochlorite. Amuchina exerts bactericidal, viricidal, and fungicidal effects on a variety of pathogens through generation of hypochlorous acid. Amuchina 10% (ExSept plus) and Amuchina 5% (ExSept) have been found to be as effective as povidone-iodine 10% in preventing exit-site infections [254]. In an open-label, single-center prospective pediatric study, Amuchina 50% was compared to amuchina 3%. The rates of exit-site infections were similar in both groups. Amuchina 3% is the most cost effective option compared to Amuchina 50%, povidone iodine 10% or chlorhexidine 4% [255]. Amuchina may occasionally cause scab formation and exit-site irritation [254].

A dressing cover for 6–12 months after implantation is recommended. Continued use of dressings is indicated for infected exit sites or likely to be contaminated. Patients should avoid submersion in water, particularly in a Jacuzzi, hot tub, or public pool, unless watertight exit protection can be implemented. The surrounding skin is coated with a skin protector and secured with Tegaderm®. Prolonged submersion in water containing high concentrations of bacteria frequently leads to severe infection with consequent loss of catheter. Swimming in the ocean, and well-sterilized private pools, is less dangerous. Exit care must be performed immediately after a shower or water submersion, with particular attention to obtaining a well-dried exit. Patients with the swan-neck presternal catheter may take a hot tub bath without exit-site submersion. Because of this feature this catheter was dubbed the "bath-tub" catheter [3].

Antibiotic Prophylaxis

Exit-site infections are commonly caused by *S. aureus* and *P. aeruginosa* [242–245]. Mupirocin is a carboxylic acid that inhibits bacterial protein synthesis by binding isoleucine t-RNA synthetase and is active against staphylococci and streptococci but not enterococci or Gram negatives [256]. Data supports the use of mupirocin at the exit site to decrease exit-site infections and peritonitis by *S. aureus* [207, 257–260]. The usual recommendation is to apply mupirocin daily after cleansing. Once-weekly application of mupirocin to the exit site has also been shown to be effective in decreasing exit-site infections and peritonitis episodes comparable to those obtained with daily application [261, 262].

Alternative to mupirocin, gentamicin cream [263] and ciprofloxacin otologic solution [237] are effective in reducing the incidence of *S. aureus* as well as Gram-negative exit-site infections. Bernardini et al. randomized 133 individuals to exit-site mupirocin or gentamicin cream [263]. Catheter infection rates were 0.23/yr with gentamicin cream versus 0.54/yr with mupirocin ($p = 0.005$). *S. aureus* exit-site infections were infrequent in both groups (0.06 and 0.08/yr; $p = 0.44$). While there were no pseudomonal exit-site infections in the gentamicin group, there were 0.11 episodes per patient year in the mupirocin arm. Peritonitis rates were 35% lower in the gentamicin arm, with a striking decrease in Gram-negative peritonitis. Montenegro et al. randomized 164 individuals to exit-site care with soap and water only versus exit-site care with soap and water plus application of 1 mg ciprofloxacin (0.5 mL otologic solution) [237]. Ciprofloxacin reduced exit-site infections to 0.06 episodes per patient-year of exposure in contrast to 0.41 episodes in the control group ($p = 0.001$). *S. aureus* infections were significantly reduced and none of the treated patients developed pseudomonal exit-site infections.

Table 14.9 Antibiotic protocol options for preventing exit-site infections

1. Exit-site mupirocin:
a. Daily after cleansing in all patients
b. Daily after cleansing in carriers only
c. In response to a positive exit-site culture for *Staphylococcus aureus* denoting carriage
2. Intranasal mupirocin twice per day for 5–7 days:
a. Every month, once patient identified as a nasal carrier
b. Only in response to positive nose culture
3. Exit-site gentamicin cream daily in all patients after cleansing

Source: Reproduced with permission from [223]

The nasal carriage of *S. aureus* is also a risk factor in peritoneal dialysis–related infections [197, 200, 204, 205]. The treatment of *S. aureus* nasal carriage with intranasal mupirocin twice a day for 5–7 days has been shown to decrease the incidence of *S. aureus* exit-site infections [204–206], and in some studies peritonitis and catheter loss [205, 206]. On meta-analysis, intranasal mupirocin was found to have no benefit on decreasing peritonitis rates and catheter loss [264]. Periodic retreatment is frequently necessary because of a high recolonization rate [204–206]. This may be done routinely at monthly intervals or based on periodic screening. Since the strains of *Staphylococcus* colonizing the exit site may be different from the nose [265], exit-site prophylaxis may be the preferred option and is more convenient. An alternative to intranasal mupirocin is the use of oral rifampin in a dose of 600 mg/day for 5 days every 3 months to reduce *S. aureus* exit-site infections [207, 208]. In a randomized study, mupirocin and rifampin were equally effective in reducing *S. aureus* peritonitis and catheter loss, however, rifampin was often poorly tolerated [207]. In a meta-analysis of studies on prophylaxis against *S. aureus*-related infections in patients on dialysis, resistance to rifampin ranged from 0 to 18.2% and the drug had to be discontinued in 6.6% of patients due to toxicities [266]. The overall benefit of mupirocin prophylaxis (nasal and exit-site) were evaluated in another meta-analysis; there was a highly significant relative risk reduction of 37% for all *S. aureus* infections, 34% for peritonitis, and 38% for exit-site infections [267].

There are few side-effects associated with the mupirocin, mainly nasal irritation and discharge for the nasal route [204]. Exit-site mupirocin ointment can structurally damage polyurethane and should be avoided with these catheters [268]. An increasing prevalence of mupirocin resistance is being reported [269, 270]. Perez-Fontan has reported that high-level resistance to mupirocin (defined as an MIC $\geq$512 μg/mL) increased from nonexistent in the period 1990–1996 to 12.4% in 1999–2000. He also noted that the accumulated incidence of *S. aureus* exit-site infection in the period 1997–2000 was 32.3% in patients colonized by mupirocin-resistant *S. aureus* as compared with 14.5% in those colonized by mupirocin-sensitive *S. aureus* ($p = 0.03$), suggesting a substantial impact of the development of resistance [269]. In these reports, none of the isolates were methicillin-resistant [269, 270] nor are there reports of development of cross-resistance [271]. Prolonged usage and multiple intermittent courses of mupirocin appear to be the factors most frequently associated with the development of mupirocin resistance [271]. However, one study that examined mupirocin resistance over a 7-year period reported no increased prevalence in mupirocin resistance over this time period [272]. Programs should perform periodic surveillance to detect the emergence of resistant strains.

The International Society of Peritoneal Dialysis recommendations on antibiotic protocols for preventing exit-site infections are reproduced in Table 14.9 [223].

Early Complications Related to Peritoneal Access

Early complications post-soft catheter insertion are similar to those after implantation of the rigid catheter, but their frequency is lower, particularly with surgical, peritoneoscopic, or laparoscopic insertion. Blood-tinged dialysate is common postimplantation but severe bleeding occurs very rarely with surgical insertion. Dialysate leaks are unlikely if ambulatory peritoneal dialysis is postponed for at least 10 days after implantation [273]. This complication is particularly rare with the Toronto Western Hospital, swan-neck Missouri abdominal, swan-neck presternal, and Lifecath® column disc catheters. Early leak is usually external and may be confused with serous drainage from the exit. A diagnosis of a leak is supported by a higher glucose concentration in the drainage compared to the simultaneously measured blood glucose concentration.

Poor dialysate return is usually due to catheter obstruction if loss of siphon or tubing occlusion is ruled out. The most common reason of catheter obstruction is occlusion of the tip by bowel and/or bladder or intraluminal formation

Table 14.10 Early catheter obstruction

Cause	Prevention/treatment
Occlusion by bowel	Laxatives
Occlusion by bladder	Empty bladder
Clot	Rinse out blood, heparin, urokinase, dislodge
Omental wrap	Partial omentectomy
Multiple adhesions	Adhesiolysis
Kink in the tunnel	Surgical correction

of clot (Table 14.10). Emptying the bladder and using laxatives may restore catheter function if there is obstruction by bladder or bowel. Clot may be prevented by rinsing out blood from the peritoneal cavity and using heparin or can be dislodged by forceful injection through the tubing into the peritoneal cavity or pulling by suction using a syringe filled with heparinized saline. If these maneuvers are unsuccessful the catheter may be filled with urokinase (Abbokinase) 5,000 IU, diluted in normal saline. Thrombolytics like tissue plasminogen activator and urokinase may open the obstruction in 10–15% of cases [274–277]. Using high pressure during fluid infusion, Hashimoto et al. [278] were able to open six catheters occluded by clots. Catheter kinking in the tunnel is usually associated with two-way obstruction, is recognizable on abdominal X-ray in two views, and requires surgical correction as soon as diagnosis is made. If the catheter is not kinked, but does not function for 2 weeks, omental wrapping or multiple adhesions are most likely and omentectomy or adhesiolysis using laparoscopy may be required.

A reversed one-way peritoneal catheter obstruction, in which the fluid can be drained but the next infusion cannot be performed, is extremely rare. In one such case, the catheter tip was obstructed with a clot which caused inflow obstruction. The catheter tip was obstructed with a clot, which caused inflow obstruction. This clot was removed by suction with a syringe. We speculated that the clot was firmly anchored in the catheter tip, and that only a few proximal side-holes were open. The outflow was not obstructed because the catheter tip must have been located in a large pocket of free peritoneal space. The clot behaved like an accordion. During drainage the clot became stretched and narrowed (like an accordion bellow in extension) and fluid was able to flow through some of the side-holes. During infusion the clot buckled up and widened (like a compressed accordion bellow), completely occluding the central lumen and side-holes [279].

Another reason for obstruction may be catheter adherence to the peritoneum. This complication was found in children who have undergone partial omentectomy at the time of insertion of a single-cuff, straight Tenckhoff catheter. Relocation of such catheters may be attempted with a so-called “whiplash” technique [280]. After localization of the catheter adherence site, using a strict sterile technique, a blunted steel trochar is inserted into the catheter and gently advanced until the trochar tip is 5–7 cm proximal to the tip of the catheter. Using a deep cuff as a fulcrum, and using short and rapid whiplash motions, the catheter is then freed from the adherence point. The catheter tip is then, under fluoroscopy, relocated to a new site. A modification of this method using a pliable copper thread was successfully used in adults [281]. A catheter that has migrated to the upper abdomen may be relocated using a guidewire [282–284]. Although these methods may obviate the need for surgery, they are not without risk. The guidewire may break during manipulations, may perforate the catheter, and may lead to recurrent peritonitis.

Catheter migration out of the true pelvis is seen frequently on abdominal X-rays done for various reasons in patients with functioning catheters. While about 20% of X-rays showed the catheter tip translocated to the upper abdomen, only 20% of these translocated catheters (4% of the total) were obstructed or malfunctioning. The remaining functioning malpositioned catheters were either permanently translocated or repositioned spontaneously to the true pelvis. About 3% of catheters in our series were obstructed with the tip in the true pelvis [285].

While the great majority of malpositioned catheters are not obstructed, a catheter with its tip in the upper abdomen is still about six times more likely to be obstructed than a normally positioned catheter. The migration of the catheter tip may, however, be the result of the obstruction rather than its cause; omentum entangling the catheter tip may be responsible for its translocation.

Repositioning of the internal catheter segment is best done surgically using a laparoscopic method (see above). In our experience, if this method fails to restore catheter function because the peritoneum is not usable for peritoneal dialysis because of massive adhesions, catheter relocation or replacement in such a situation is worthless. The patient must be transferred to hemodialysis.

Viscus perforation is unlikely with surgical catheter insertion. Early peritonitis with a soft catheter is half of that reported with a rigid catheter, even in treatment of acute renal failure [126]. Abdominal pain is more likely with straight catheters due to “jet effect” and tip pressure, as discussed in the section on infusion/pressure pain.

Late Complications Related to Peritoneal Access

Factors influencing catheter complications have been discussed earlier. Complications are not randomly distributed throughout the life of the catheter. Whereas leaks and catheter malfunction occur shortly after catheter implantation, infectious complications lead to catheter failure later.

Exit-Site Infections

The use of a classification system facilitates early diagnosis of exit problems, and treatment can be more specific. Exit-site care and treatment for each appearance category are summarized in Table 14.11.

Table 14.11 Exit-site treatment and care for each category of exit-site appearance

	Equivocal infection	Acute infection	Chronic infection	Cuff infection
Evaluation	Culture and sensitivities on peri-exit smear; Gram stain	Culture and sensitivities on exudate; Gram stain	Culture and sensitivities on exudate; Gram stain	Palpation of cuff and tunnel; culture and sensitivities and Gram stain of exudate (spontaneous or after pressure on cuff); ultrasound of cuff/tunnel
Initial therapy	Cauterize slightly exuberant granulation tissue. Topical mupirocin. Exit care daily; clean with mild disinfectant soap; do not use strong oxidants on granulation tissue; use a sterile absorbent dressing.	Cauterize slightly exuberant and exuberant granulation tissue. First-generation cephalosporin for Gram-positive organisms; quinolone for Gram-negative organisms; vancomycin for methicillin-resistant *S. aureus*. Exit care daily or b.i.d.; clean with mild disinfectant liquid soap or nonionic surfactant agent; do not use strong oxidants on granulation tissue; use a sterile, absorbent dressing.	Cauterize slightly exuberant and exuberant granulation tissue. First-generation cephalosporin for Gram-positive organisms; quinolone for Gram-negative organisms; vancomycin for methicillin-resistant *S. aureus*. Exit care daily or b.i.d.; clean with mild disinfectant liquid soap or nonionic surfactant agent; do not use strong oxidants on granulation tissue; use a sterile, absorbent dressing.	Cauterize proud flesh. Initial antibiotic therapy based on Gram stain results.
48 h	Change to Neosporin, gentamicin, or chloramphenicol ointment if Gram-negative organisms on culture.	Adjust therapy according to culture and sensitivities.	Adjust therapy according to culture and sensitivities.	Adjust antibiotic according to culture and sensitivities.
Follow-up	If no improvement in 2 weeks, change to systemic antibiotic based on initial culture and sensitivities. Continue therapy 7 days past achieving a good appearance.	Evaluate weekly; reculture if no improvement. Continue to treat for 7 days after achieving a good appearance.	Evaluate every 2 weeks; reculture every 2 weeks if no improvement on appropriate therapy. Add synergistic drug or change antibiotic according to culture and sensitivities. If infection recurs repeatedly after achieving a good appearance: (a) consider chronic antibiotic suppression; (b) if no improvement after a month of treatment, suspect cuff infection and treat as such. If accompanying peritonitis, remove catheter.	Re-evaluate every 2 weeks; reculture monthly. If no remission: (a) consider cuff shaving; (b) consider catheter replacement. If accompanying peritonitis, remove catheter.

Modified from [241] with permission

Acute Exit-Site Infection

A culture of exit-site exudate or, if there is swelling/erythema without expressible exudate, a smear culture of the skin surrounding the exit should be taken as soon as a clinical diagnosis of an acute exit-site infection is made. Recommendations for the care of infected exit-sites are based on sound surgical practices and anecdotal experiences. Increasing the frequency of dressing changes to once or twice a day helps the healing process, especially in those with copious drainage. Nonirritating solutions (e.g., nonionic surfactant) are preferred cleansers to remove drainage and reduce the number of microorganisms. An infected exit should be covered with a sterile nonocclusive dressing to absorb drainage, protect against trauma, and shield against superinfection.

An attempt may be made to treat early infections with erythema and no drainage with topical treatments. These treatments include application of soaks to the exit twice to four times daily, as well as the application of dry heat. Soaking solutions include normal saline, hypertonic saline, sodium hypochlorite, dilute hydrogen peroxide, povidone-iodine, and 70% alcohol [223, 249, 286, 287]. Local applications of povidone-iodine ointment, mupirocin, and Neosporin® cream, ointment, or ophthalmic solutions have been recommended [223]. Topical antibiotics are of limited value in treating acute or chronic infection with copious drainage because of the inability to achieve sufficiently high local concentrations [288]; however, topical antibiotics are helpful once drainage diminishes.

Depending on the clinical appearance, empiric antibiotic therapy may be initiated immediately or delayed until the results of the culture are available. Prior cultures or the Gram stain may guide initial therapy. Gram-positive organisms are treated with an oral penicillinase-resistant penicillin, cephalexin, or sulfamethoxazole trimethoprim. In slowly resolving or particularly severe-appearing *S. aureus* exit-site infection, rifampin 600 mg daily is added. Oral antibiotics are equally effective as intraperitoneal antibiotics for most ESI with the exception of methicillin-resistant *S. aureus* [223]. Vancomycin should be avoided in the routine treatment of Gram-positive exit-site infection and tunnel infections to prevent emergence of resistance. Gram-negative organisms may be treated with oral quinolones such as ciprofloxacin. The presence of *P. aeruginosa* should prompt the use of two antibiotics with different mechanisms of action such as ciprofloxacin and ceftazidime or an aminoglycoside. These infections are often refractory to treatment and have frequent relapses [223, 289]. Very often *Pseudomonas* exit-site infections resolve only after catheter removal. Antibiotic therapy should be continued until the exit site appears entirely normal, with a minimum of 2 weeks of therapy.

Exuberant granulation tissue (proud flesh) is cauterized with a silver nitrate stick, a procedure widely used in surgical practice, veterinary and human [288, 290]. No more than one or two applications are necessary in most patients with acute infection. This procedure speeds up the healing process and facilitates epithelialization. Cauterization should be restricted to granulation tissue only, and accidental touching of the adjacent epithelium should be avoided. Use of a magnifying glass aids in precise cauterization. This can be done safely by a physician or nurse [291].

Catheter immobilization is a sound practice providing protection against accidental trauma. Trauma leads to bleeding, and blood is a good medium for facilitating growth of microorganisms. Catheter immobilization should be continued or implemented during the acute infection stage.

An ultrasound of the exit site is indicated to evaluate for presence of tunnel and cuff involvement if the infection fails to respond to 2 weeks of appropriate antibiotics. Since patients with *S. aureus* and *Pseudomonas* sp. exit-site infections have a high incidence of cuff and tunnel involvement, an ultrasound examination when the cultures are reported should be a consideration. Another indication for ultrasound is the presence of simultaneous exit-site infection and peritonitis [292].

Most acute infections respond favorably to therapy. An exit-site with an acute infection in association with proud flesh and bleeding requires prolonged antibiotic therapy. Association with a positive nasal culture had no influence on the outcome. Conditions that delay healing or make therapy ineffective are cuff and/or tunnel infection, infection due to a resistant organism or a virulent pathogen, and patient noncompliance [223, 293]. Recurrent infections that progress to chronic infection and/or cuff infection are associated with a poor prognosis. Catheter removal is indicated when acute exit-site infection leads to tunnel infection and peritonitis. Management of cuff infection is discussed later in this section.

Chronically Infected Exit Site

The work-up leading to the proper diagnosis of a chronically infected exit site is similar to that performed to diagnose acute infection. These infections are hard to treat. Once the culture and antibiotic sensitivity results are available, an appropriate antibiotic should be started. A combination of synergistic antibiotics is preferred to a single agent, to avoid emergence of resistant organisms, since the therapy is given over a prolonged period. In chronic infection, the bacterial flora or the antibiotic sensitivity may change during the course of treatment. Therefore, an unresponsive exit site may

have to be cultured repeatedly for timely diagnosis. The response to treatment is usually slow. An ultrasound of the catheter tunnel may be indicated to evaluate for cuff infection. The features of the chronic infection change very slowly to those of an equivocal exit and then eventually to those of a good exit site.

The antibiotic therapy and local care of the exit site are continued until the desired features of a good exit are achieved. In some cases, exit features change to equivocal and remain as such for a long time. In such instances, the systemic antibiotic is discontinued and replaced with a topical antibiotic. Chronic infection requires repeated cauterization of exuberant granulation tissue. Typically, weekly cauterization for several weeks is necessary. The cauterization is continued as long as the proud flesh persists. The cauterization will discolor the proud flesh from red to gray. Some cases of chronic infection may require long-term (many months) suppressive doses of a systemic antibiotic. Typically, these cases show reinfection on discontinuing the systemic antibiotic. It is likely that such cases represent undiagnosed cuff infection. Chronic exit-site infections may require catheter removal.

Local care is similar to that used in treating acute infection. After achieving the features of an equivocal exit, the frequency of local care may be reduced to once a day.

Equivocal Exit

The equivocal exit site is a subclinical form of infection. If left untreated, most equivocal exits will progress to acute infection. Therefore, aggressive management of equivocal exits assumes great importance. Aggressive local care with a topical antibiotic may cure most equivocal exit sites. Exits with external, slightly exuberant granulation tissue, which usually progress to acute infection, require systemic antibiotics. Cauterization of the slightly exuberant granulation tissue in the sinus may be necessary.

An acute infection may acquire equivocal features during the recovery phase. Such an exit site warrants less aggressive therapy compared to one with acute infection; the key to therapy being daily local care while systemic antibiotics may be discontinued.

Local therapy with topical antibiotics is the mainstay of treatment for an equivocal exit site. A topical antibiotic is chosen based on the exit swab culture results. The topical antibiotics that we have successfully used include mupirocin, Neosporin®, gentamicin, chloramphenicol, and tobramycin. This effectiveness is due to the absence of copious drainage from the sinus tract. Systemic antibiotic may be used in cases unresponsive to topical therapy. Response to therapy is usually excellent, with cure occurring in almost all instances.

Good and Perfect Exit

The care of these exit sites has been discussed earlier in this section. Catheter immobilization, protection from trauma, use of liquid soap and water for daily care, and use of Shur-Clens® to remove large, irritating crust are appropriate measures to prevent infection. In our experience, a perfect exit is unlikely to become infected unless severely traumatized or grossly contaminated after submersion in water loaded with bacteria.

Traumatized Exit

Bleeding is a common squeal of trauma. Extravasated blood is a good medium for bacterial growth. Bacteria that have colonized the exit multiply rapidly in the presence of decomposing blood and infect the disrupted tissue. Infection may occur as early as 24–48 h after trauma. The prompt administration of an antibiotic, chosen based on the history of skin colonization, may prevent acute infection. In the absence of the information about previous skin colonies, an antimicrobial agent sensitive to Gram-positive organisms, such as a cephalosporin or a quinolone, may be chosen. Therapy may have to be continued for about 7 days after achieving a good appearance. Aggressive treatment is necessary in every instance of trauma reported by the patient. Local care requires gentle cleansing of all blood from the exit site.

External Cuff Infection with or Without Exit Infection

Ultrasound examination of the tunnel is a valuable tool in the diagnosis of cuff infection. While positive findings with ultrasound examination help to establish a diagnosis of tunnel infection, a negative examination does not rule out the existence of an infection [294]. Cuff infection responds to therapy slowly, if at all, and a complete cure is unlikely. A sonolucent zone around the external cuff 1-mm thick following a course of antibiotic treatment and involvement of the proximal cuff are associated with poor outcomes [295]. Vychytil has suggested that in *S. aureus* tunnel infections, if sequential ultrasounds done every 2 weeks do not show a 30% decrease in the hypoechoic area around the cuff, the catheter should be removed [292].

Local care has to be given aggressively. Among the surgical options is catheter removal with simultaneous or delayed catheter replacement [296, 297]. Deroofing of the sinus tract and external cuff shaving [298–301] and replacement of the external tubing segment by catheter splicing [302–304] are other surgical options. The latter two options allow for the continuation of peritoneal dialysis without the need to switch to hemodialysis. In our experience cuff shaving prolonged catheter life for approximately 6–12 months [291]. These temporary measures may be suitable for patients who are expected to stay on therapy for a short period, e.g., patients awaiting transplant; however, cuff infection is a strong indicator for catheter removal in long-term peritoneal dialysis patients. Anecdotal reports suggest that cuff shaving may provide better results in presternal catheters [305]. This may be related to the presence of three cuffs and a long tunnel in the presternal catheter. Shaving of the subcutaneous cuff leaves two cuffs as a double barrier against peri-luminal bacterial penetration.

Peritonitis

Peritonitis on peritoneal dialysis usually develops because of touch contamination or pericatheter spread of bacteria. Touch contamination causes peritonitis by skin commensals such as coagulase-negative *Staphylococcus*, Corynebacterium, diptheroids, and occasionally Gram-negative organisms [193, 306, 307]. Exit-site and tunnel infections are associated with a pericatheter spread of infection [308]. In a trial examining the risk factors for peritonitis, the development of an exit-site infection doubled the risk of subsequent peritonitis [309]. The organisms commonly associated with such infections are *S. aureus* and *P. aeruginosa* [242–245]. Occasional patients develop peritonitis due to hematogenous seeding, bowel perforations or gynecological spread of organisms. Bowel trauma is a known catheter complication [310].

Tunnel infections often require removal of the catheter without which the patient may suffer from recurrent or relapsing peritonitis from the same organism. Even with exit-site infections, occult tunnel infections may be present may cause a high failure rate to therapy. Another cause of recurrent or relapsing peritonitis is the development of bacterial biofilm layers on the catheter. Bacterial biofilms are microbial colonies enclosed in a self-produced polymeric matrix and adherent to the catheter. *S. aureus* and coagulase-negative *Staphylococcus* are the most common organisms forming biofilms. Bacteria in the biofilm are in a sessile form and are intermittently shed in a planktonic form, which can be pathogenic. Biofilm infections are often slow to produce symptoms. Mature biofilms develop resistance to antibiotics, phagocytes, and biocides [311]. The poor penetration of antibiotics into the biofilm may explain antibiotic resistance. Alternatively, the bacteria may enter into a nongrowing state or a spore-like state in which they are protected from killing [312, 313]. Relapsing peritonitis has also been reported due to colonization of presternal catheter at the site of titanium connector. In this case, a removal of the chest segment of the catheter resulted in resolution of relapsing peritonitis [314].

Infusion or Pressure Pain

Some patients may experience pain with infusion of dialysate. This pain may be due to the acidic pH (pH 5.2–5.5), hyperosmolality, or temperature of conventional dialysate [315]. Localized pain may result from irritation from the catheter tip as it rests against the pelvic wall or intra-abdominal organs [316]. The jet effect of rapidly flowing dialysis solutions may also cause abdominal pain. In some rare instances, compartmentalization from adhesion formation around the catheter may cause severe abdominal pain [317].

Coiled catheters are less likely to induce abdominal pain than straight catheters because more of the solution flows shower-like through side-holes, with only part of it through the main lumen that is not in direct contact with the peritoneal membrane. Moreover, the poking force of the coiled catheter is smaller than that of the straight one because the coiled intraperitoneal segment is more flexible. Finally, the larger contact area of the coiled catheter with the parietal peritoneum further reduces the pressure compared to the straight catheter tip.

In the majority of cases, the pain is transient and disappears within a few weeks. Assessment of the catheter by routine radiographs, contrast catheterograms, or CT-peritoneography may be indicated. Table 14.12 shows the maneuvers, which may be used to alleviate the pain. Decreased infusion rate is frequently helpful. If pain occurs only at the beginning of inflow and the end of outflow, incomplete drainage and/or tidal mode for nightly peritoneal dialysis may be successful. Alkalization of conventional dialysate with sodium bicarbonate or use of local anesthetics is sometimes effective, but at the potential cost of increased peritonitis and therapy burden. The use of bicarbonate and bicarbonate/lactate solutions having a physiological pH has been shown to reduce infusion pain [315]. If all these maneuvers are ineffective, the catheter has to be replaced. The replacement catheter should be a coiled one and the catheter should be implanted in such a way that no undue pressure is exerted at the tip.

Table 14.12 Maneuvers to alleviate infusion pain

Slower infusion rate
Incomplete drainage
Tidal mode for nightly peritoneal dialysis
Solution alkalization (sodium bicarbonate: 2–5 mEq/L)
Bicarbonate or bicarbonate/lactate peritoneal dialysis solutions
1% lidocaine – 2.5 mL/L (50 mg/exchange)
Catheter replacement

External Cuff Extrusion

A cuff positioned close to the exit site predisposes it to extrusion. There are at least two forces favoring cuff extrusion (Table 14.13): 1) the pushing force of catheter resilience and 2) pulling and tugging on the catheter. The tendency of a straight catheter implanted in an arcuate tunnel to straighten, due to resilience, plays the most important role in cuff extrusion (Fig. 14.40). Manipulation of the catheter with frequent CAPD exchanges also contributes to this complication. There is also a possibility that high hydrostatic pressure in the abdomen with the constant presence of fluid in the peritoneal cavity, while the patient is ambulatory, also tends to extrude the external cuff.

The external cuff should be implanted approximately 2–3 cm beneath the skin as a compromise between the need of a short sinus tract to prevent infections but not so short as to favor cuff extrusions [1, 223]. Also, resilience forces should be eliminated by creating the tunnel in a shape similar to the shape of the catheter. Tugging on the catheter should be avoided. It is extremely important to avoid resilience forces pushing on the cuff if implanting it

Table 14.13 Causes of cuff extrusion

Catheter resilience
Pulling and tugging
Intra-abdominal pressure?

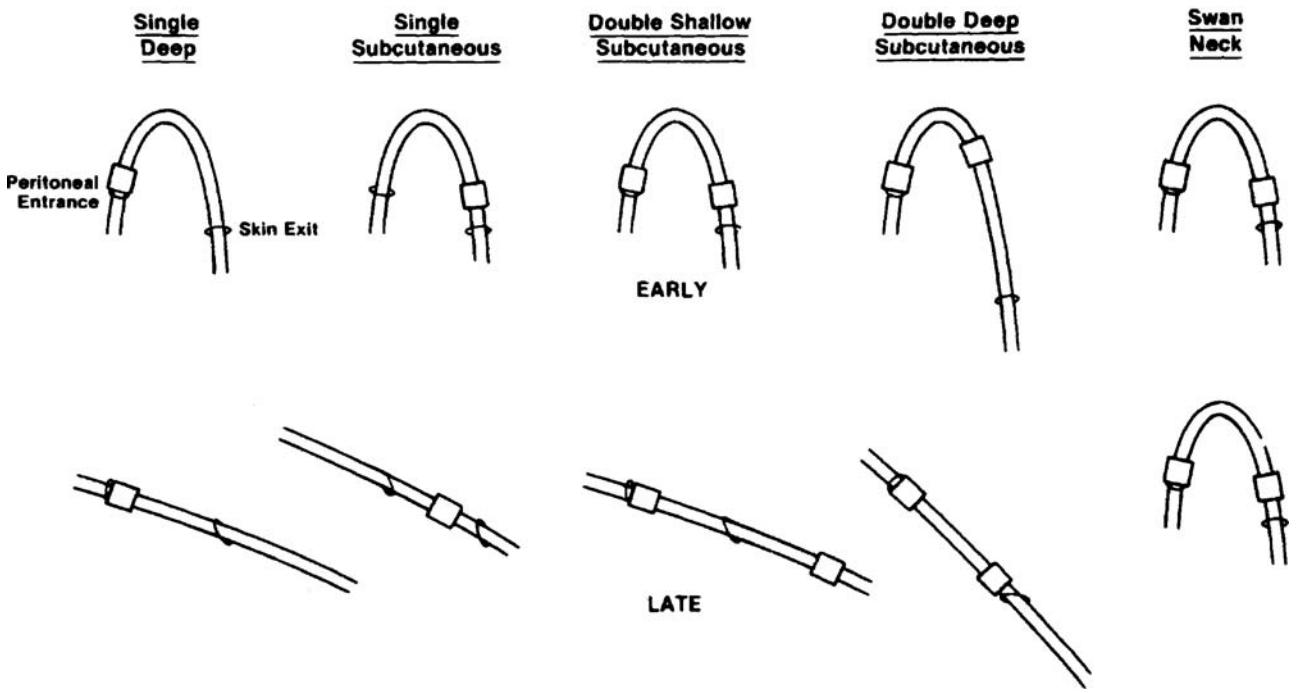

Fig. 14.40 Straight and swan-neck catheters in arcuate tunnels. Upper panel shows catheter configuration immediately after implantation, lower panel portrays catheter shape several months later. Straight catheters forced into arcuate tunnels gradually assume natural, straight configuration. Single-cuff catheters do not extrude cuffs. With long distance between cuffs and shallow subcutaneous tunnel, the external cuff extrusion is inevitable (center), whereas short distance between cuffs and deep position of the subcutaneous cuff precludes its extrusion. Swan-neck catheter maintains its shape

relatively close to the skin exit. The catheter should not be implanted in a site with subcutaneous edema, to avoid cuff extrusion once the edema is resolved. We also recommend a 2-week period of wound healing occur before beginning dialysis training. This helps to seal and anchor the Dacron® cuffs by tissue ingrowth.

If the cuff is not infected it is left alone; however, the cuff usually becomes infected during this process and requires systemic antibiotics or even surgical intervention. If there is no peritonitis and no deep cuff infection then the catheter may be saved, at least for some time, by shaving off the infected superficial cuff [298, 301]. Infection is another cause of cuff extrusion. In this instance the cuff becomes infected while still in the sinus, and is extruded by tissue retraction around the cuff. Two such extrusions were observed with swan-neck Missouri abdominal catheters [83]. We also observed a patient who traumatized her presternal catheter and developed a superficial and mid-cuff infection leading to a tunnel infection. The tunnel was opened and drained and the catheter was shortened to a "one cuff" (deep) catheter which continued to function years after the drainage procedure.

Catheter Obstruction

"Capture" of the catheter by active omentum may cause outflow obstruction. Obstruction from this cause, in the absence of peritonitis, when it occurs is usually a postoperative event (related to a new catheter). We have never seen an obstruction (in the absence of peritonitis) due to omental "capture" as a late event. We believe that Silastic® is more prone to attract omentum very early. In due course of time, with or without use, a proteinaceous (not bacterial) biofilm catheter coating may make the Silastic® less "foreign" to omental tissue. Slow drainage due to catheter translocation, obstruction by bowel, or fibrin clot formation occurs from time to time in some patients. Laxatives and/or addition of heparin 500 U/L of dialysis solution are usually successful in restoring good catheter function. Some patients have permanently translocated catheter out of the true pelvis. If the catheter functions (even with slower drainage), we do not attempt to reposition the catheter. If catheter does not function after implementing simple maneuvers, more aggressive measures, similar to those described in the section on early soft catheter complications should be tried (see above).

An unusual cause of Cruz catheter blockage, which occurred 4 weeks after initiation of dialysis as a result of the tip wrapping by a fallopian tube, has been reported [318]. The fimbriae of the oviduct penetrated through the side-holes of the catheter and occluded the central lumen. Catheter function was restored surgically. A high dialysate flow and bigger side-holes of the polyurethane device (the Cruz® catheter) as compared to silicone rubber catheters might have contributed to this complication.

Catheter-Tip Migration

One- or two-way catheter obstruction is usually the result of catheter wrapping by the omentum. The best condition for dialysate drainage is created with the catheter tip in the true pelvis because, in the majority of people, the omentum does not reach to the true pelvis. Tenckhoff recommended a caudal direction of the intraperitoneal catheter segment to prevent catheter tip migration out of the true pelvis [89]. If the exit site is directed caudally and a straight tunnel points cephalad the catheter *must* have an intraperitoneal bend to place the tip near the true pelvis, and the tip can easily translocate out of the true pelvis due to the silastic "shape memory." The internal cuff operates like a fulcrum on which resilience forces flip the catheter tip into the upper abdomen (Fig. 14.41). If the tip translocates to the left upper abdomen the peristalsis of the descending colon may restore proper position of the tip; however, a tip translocated to the right upper abdomen usually does not return to the proper position because the forces of both catheter resilience and ascending colon peristalsis push the tip upwards. In support of this hypothesis are observations that, when a catheter is implanted with a straight subcutaneous tunnel, with the external exit directed downwards and the intraperitoneal entrance directed upwards, even if the catheter tip is placed into the true pelvis during insertion, it migrates out to the upper abdomen significantly more frequently compared to the opposite tunnel direction [80, 319]. Our experience indicates that the dominant factor in catheter-tip position is the resilience force of the catheter. To avoid the unfavorable influence of resilience forces on the intra-abdominal catheter segment, the catheter needs to be molded in the shape in which it is to be implanted in the tunnel.

The problem of tip migration was approached differently by Oreopoulos et al. [40], who provided the intraperitoneal segment of the catheter with two silicone discs. Once the catheter is in the true pelvis, these discs hinder translocation of the catheter tip. Recently, Di Paolo et al. [48] provided the catheter tip with a small, tungsten weight incorporated into the silicone rubber to prevent catheter migration out of the true pelvis. The migration rate of these

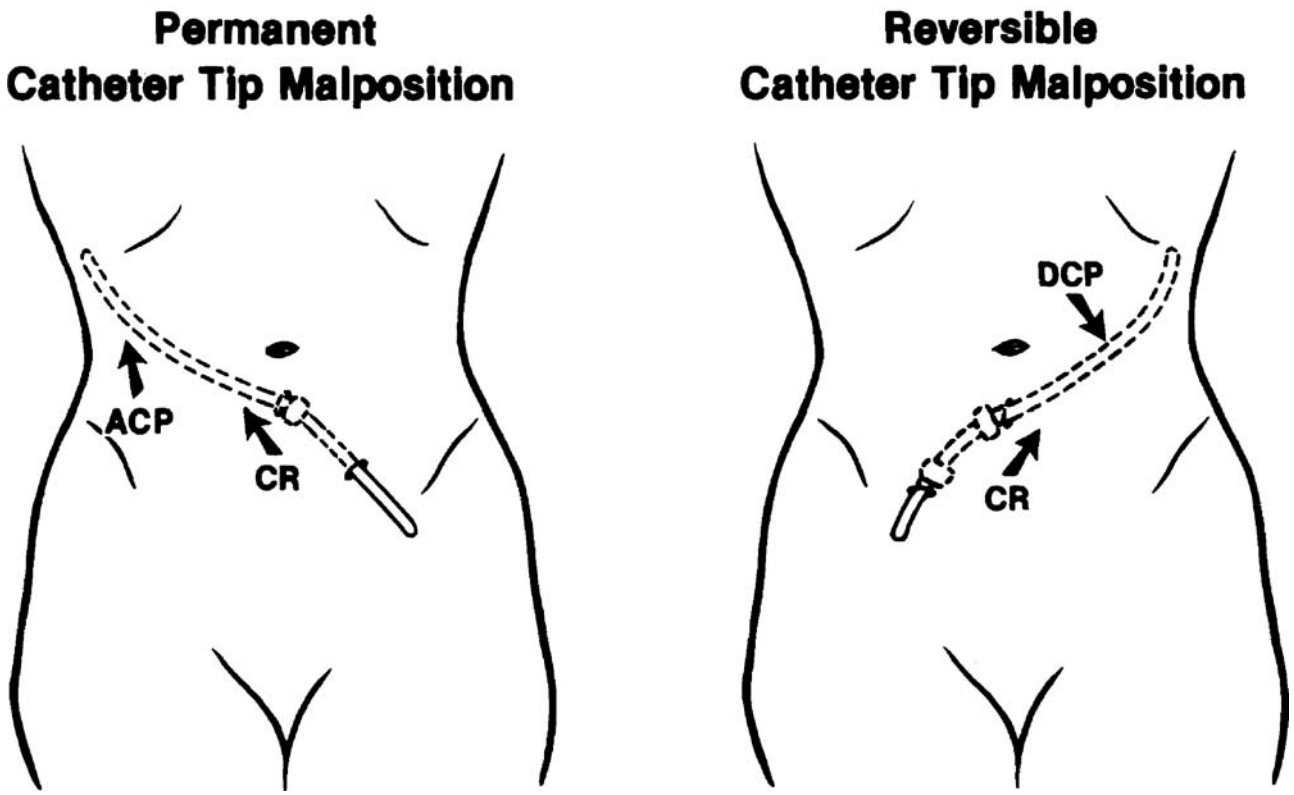

Fig. 14.41 Straight catheter insertion: catheter tip migration out of true pelvis with external exit directed downwards and intraperitoneal entrance directed upwards pointing either to liver or spleen. Note the tendency of catheter to assume its original shape. ACP = ascending colon peristalsis; DCP = descending colon peristalsis; CR = catheter resilience

catheters (no dislocation in 32 catheters over 468 patient-months) was significantly lower than Tenckhoff catheters (nine dislocations in 26 catheters over 415 patient-months). No detrimental effects of these weights were reported. The migration rate of Tenckhoff catheters was unusually high in this study. Catheters with a coiled intraperitoneal segment have more intraperitoneal mass and like the weighted tip catheters appear less likely to migrate out of the pelvis.

Pericatheter Leak

To avoid excessive bleeding, the catheters have frequently been inserted through the midline. In patients treated by intermittent peritoneal dialysis, dialysate leaks are rare because the intra-abdominal pressure is low in the supine position. In CAPD patients, pericatheter leaks are more frequent due to the continuous presence of dialysate in the upright position where the intra-abdominal pressure is higher. Insertion of the deep cuff into the belly of the rectus muscle, as recommended by Helfrich et al. [320], markedly reduces chances of pericatheter leak because of tissue ingrowth from the rectus muscle.

Dialysis solution leaks may occur months or even years after starting CAPD. Management of late leak is similar to that described for early leak. However, most cases of late leak are refractory to conservative therapy and require surgical repair. As discussed earlier, pericatheter leaks are more likely with the midline catheter insertion than with the insertion through the rectus muscle [80, 320]. Similar to the acute leak, this complication is rarely seen with the catheters provided with a bead and polyester flange at the deep cuff (Toronto Western Hospital, swan-neck Missouri abdominal, swan-neck presternal).

Contrary to the early leaks, which are usually external, the late leaks infiltrate the abdominal wall (Table 14.14). The acute leak causes a sudden drop of ultrafiltration and usually occurs after a sudden increase in intra-abdominal pressure (heavy lifting, coughing, or straining). The leak may be mild and intermittent. Such a leak may be difficult to localize. Immediately after leak occurrence the patient may be in good fluid balance without edema of lower

Table 14.14 Late dialysate leak

Acute	Chronic
After heavy lifting, coughing, or straining	Usually a sequela of acute leak
Sudden drop of ultrafiltration	Poor ultrafiltration
May be mild and intermittent	Fluid overload
Abdominal wall edema	Localized abdominal edema
Peau d'orange	Usually without thigh edema
Spongy feeling	

extremities. Abdominal wall edema reveals a dimpling of the skin that gives it the appearance of the skin of an orange *(peau d'orange)* and spongy feeling on palpation. Chronic leak is usually a sequel of an acute leak but may occur gradually. The patient is usually fluid overloaded due to poor ultrafiltration. A repeated peritoneal equilibration test shows unchanged solute transport characteristics but drain volume is lower [321]. Various radiologic procedures to diagnose leaks are discussed below.

Unusual Complications

Organ Erosion

Peritoneal dialysis catheters may cause hemoperitoneum by causing minor tears of the omental vessels [322]. Occasionally, a peritoneal catheter has been reported to have eroded into the mesenteric vessels leading to hemoperitoneum [323]. Peritoneal catheters may cause damage of the internal organs leading to intra-abdominal bleeding [324, 325]. Peritoneal lacerations from a catheter may lead to genital edema or other internal leaks [326]. Erosion into the small intestine, colon, and rectum are also reported on occasion [310, 327–332]. There are reports of transvaginal leak of peritoneal fluid caused by erosion of the vaginal vault by the peritoneal catheter [333, 334].

These complications are mostly described with the straight Tenckhoff catheter and the Toronto Western Hospital catheter [310, 327–331]. Though less common, such complications are also reported with coiled catheters [332]. It is thought that pressure exerted by "soft" but resilient tubing with a pointed tubing end of the straight Tenckhoff catheter or the relatively sharp silastic discs of the Toronto Western Hospital catheter leads to organ or bowel erosion. In most instances, the catheters had not been used for 1–12 weeks before the complication was diagnosed [327, 329–331]. In a dry abdomen, the peritoneum and the bowel are free to rub against the catheter leading to organ erosion.

Mechanical Accidents

Scissors or sharp objects may accidentally cut the external segment of the peritoneal dialysis catheter. Natural wear of catheters after prolonged use, repeated use of clamps, and exposure to certain disinfectants may also cause the catheter to be damaged [335]. Catheters will not self-seal if punctured and such instances may occur during implantation procedure and shaving of the cuff.

To avoid system contamination the patients are instructed to clamp the catheter immediately and cover the area with sterile gauze. If the damage is close to the adaptor, sectioning the damaged segment and inserting another adaptor is a simple procedure. If the damage leaves the catheter too short and there is at least 15 mm of tubing from the exit site, then the catheter may be saved by using the using the peritoneal catheter Peri-Patch® repair kit (Covidien, Mansfield, MA 02048 USA).

The Peri-Patch® repair kit contains a silicone rubber catheter extension with a double-barbed connector inserted in one end and a beta-cap adapter. While repairing the catheter, a sterile procedure must be strictly followed. The operator should "scrub, mask, and glove." A "circulating" nurse should be present to assist. The operating field has to be well protected with sterile towels; the catheter should be wrapped with Betadine®-soaked gauze for 5 min. The catheter is transversely cut with a sterile blade proximal to the damaged site. The catheter clamp is released and the catheter is squeezed with fingers. The patient is asked to strain, to allow dialysate flow from the peritoneal cavity. The flowing dialysate will flush any contaminant. While the fluid is still flowing, the barbed Teflon® tubing of the repair kit is inserted into the catheter as far as possible. Then the silicone rubber tubing of the repair kit is clamped to stop dialysate flow. The connection is dried with gauze. A mould is positioned over the connection and filled with sterile silicone glue. The extension tubing is connected to the catheter in the usual way. The glue cures for 72 h.

Antibiotic prophylaxis for reducing risk of peritonitis should be administered. Using this method we have been able to extend the life of seven peritoneal catheters by a mean of 26 months (range 1–87 months) [335].

Material Breakdown and Catheter Fracture

Functional integrity of the peritoneal catheter is paramount for a successful long-term peritoneal dialysis program. The age of the catheter, the material of the catheter, physical trauma, exposure to chemicals, and oxidants are crucial factors.

Dialysis catheters are made with either silicon rubber or polyurethane. While both these materials are biocompatible, each offers unique characteristics. Silicon rubber catheters cause minimal trauma to surrounding tissues and minimal leeching of plasticizers. Polyurethane has a greater strength and allows catheters to be made with thinner walls and larger lumina [336].

The polyurethane catheters are susceptible to organic solvents and plasticizers [336]. Organic solvents such as alcohol, acetone, isopropyl alcohol, dipropylene glycol methyl ether, deobase (kerosene), and benzene are found in adhesives, adhesive removers, and disinfectants. Plasticizers such as polyethylene glycol are found in ointment bases such as that of mupirocin and naturally in cholesterol and skin oils. The organic solvents can solubilize the polyurethane or cause reversible swelling of the catheter which eventually leads to surface cracking and splitting. Plasticizing agents get absorbed onto the catheters and cause softening or plasticization of the catheters [336]. These changes cause a decrease in tensile strength and lower the yield point. Caution must be exerted to avoid exposure of polyurethane catheters to these solvents and plasticizers. Mupirocin cream instead of ointment should be used in prophylaxis of exit-site infections [268, 337]. Silicon catheters are more resistant to hydrolysis due to their highly cross-linked polymer structure. However, silicone rubber catheters are more likely to be damaged by Betadine® and develop cracks or become brittle [338].

There are reports that inclusion of barium sulfate throughout the entire catheter to render it radiopaque could make the catheter brittle [338]. Currently, the catheters contain only a stripe of barium sulfate and seem to be less prone to this mode of failure.

Implanted peritoneal dialysis catheters are also subjected to mechanical trauma and biodegradation. Silicon catheters usually develop surface erosions with time, largely as a consequence of dynamic mechanical stress. In contrast, polyurethane catheters develop deep fissures and cracks that are likely caused by a combination of macrophage and leukocyte oxidation, environmental stress cracking, and mineralization [339–342].

Allergic Reactions

Among the differential diagnosis of cloudy bags is peritoneal fluid eosinophilia. This condition is diagnosed when eosinophils constitute greater than 10% of the total peritoneal fluid white blood cell count and the eosinophil count exceeds 100 cells per cubic milliliter of peritoneal effluent.

In many cases the peritoneal fluid eosinophilia occurs early after the initiation of PD and is felt to represent a reaction to the plasticizers in the PD catheter or plastic dialysate bags [343, 344]. Other causes include introduction of air or blood into the peritoneum [345], bacterial peritonitis [346], and reactions to icodextrin [347, 348] and dialysate additives. Prior reports put the incidence between 5–61%, but the incidence has significantly receded in recent years due to improvement in the quality of peritoneal dialysis materials. In most cases the eosinophilia resolves without treatment [343, 349, 350]. Coating of the catheter with proteinaceous biofilm may decrease its ability to cause an allergic reaction. Persistent cases may respond to steroids or a mast-cell-stabilizing antihistamine [351–354].

Allergic eosinophilic dermatitis due to silicone rubber is also reported [355]. Topical therapy with steroids or antihistamines may help in some patients.

Radiologic Imaging in Diagnosis of Complications

Peritoneal dialysis catheters contain radiopaque materials that allow the catheter position to be determined by simple abdominal radiographs. The catheter tip should lie deep in the Pouch of Douglas. Plain radiographs also provide information on constipation and ileus, which may impact catheter performance. Contrast catheterograms performed by injecting iodinated contrast material through the PD catheter may be useful in identifying catheter obstructions, kinks, and adhesions around the catheter.

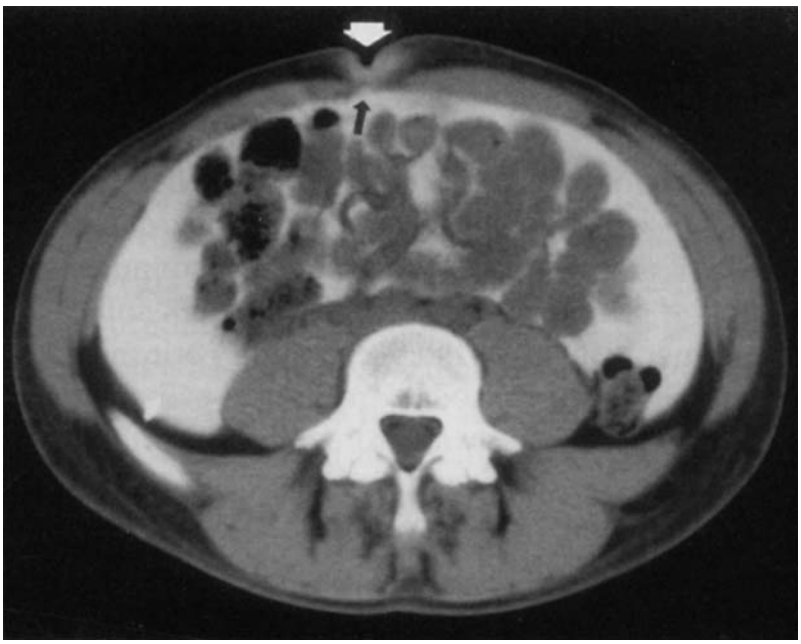

Fig. 14.42 In a CAPD patient a small area of swelling around the umbilicus occurred after lifting a 100 lb weight. CT scan of the abdomen after infusion of 2 L of contrasted dialysate shows a small amount of extravasated contrast containing dialysate in the umbilical area (white arrow)

While plain computerized tomography scans of the abdomen are useful in diagnosis of some complications, these have been replaced by CT-peritoneography. One hundred to 300 mL of iodinated contrast is added to 1,000–2,000 mL of peritoneal dialysate and instilled into the abdomen [356–358]. After instillation of this solution, the patient is encouraged to roll on his or her sides or to walk or perform other activities that may increase the intra-abdominal pressure. An option to increase intra-abdominal pressure is to increase the instilled volume of dialysate by 500 mL over the usual fill volume. A CT scan is performed approximately 2 h later. This procedure allows for the diagnosis of leaks, hernias, adhesions, and chronic peritoneal sclerosis and may identify etiologies of recurrent or relapsing peritonitis. An example of a leak in the periumbilical area without relation to the catheter is shown in Figs 14.42 and 14.43. A leak around the Tenckhoff catheter implanted through the midline is shown in Fig. 14.44.

An alternative to CT-peritoneography is MRI-peritoneography [359–361]. While the MR scans are usually performed using gadolinium-based dye added to dialysate, saline or the dialysate itself can provide a hyper intense

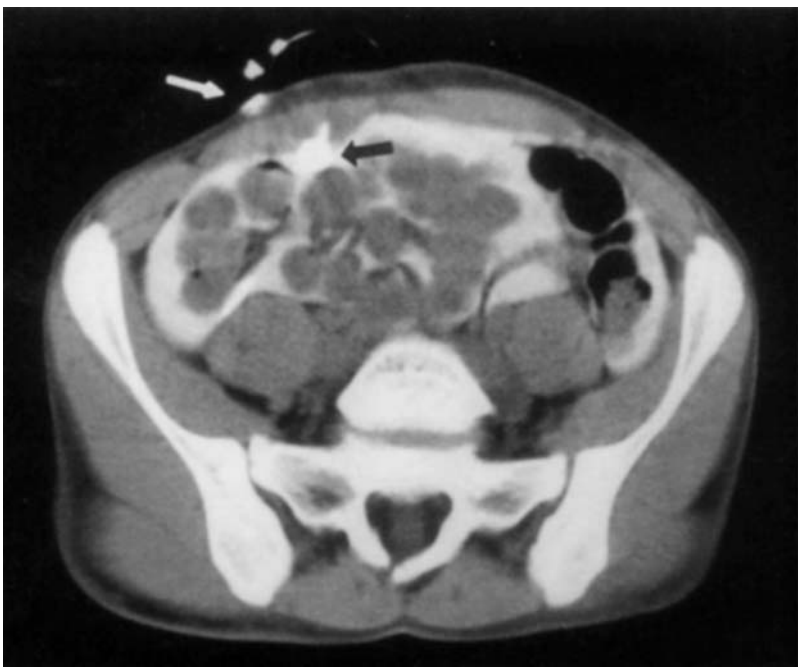

Fig. 14.43 Swan-neck Missouri catheter entering the peritoneal cavity in the vicinity of the extravasated fluid. The intraperitoneal bead (black arrow) and intramural segment leaving the subcutaneous tunnel (white arrow) are clearly recognizable. No extravasated fluid is seen around the catheter entrance into the peritoneum. Pericatheter leak is ruled out

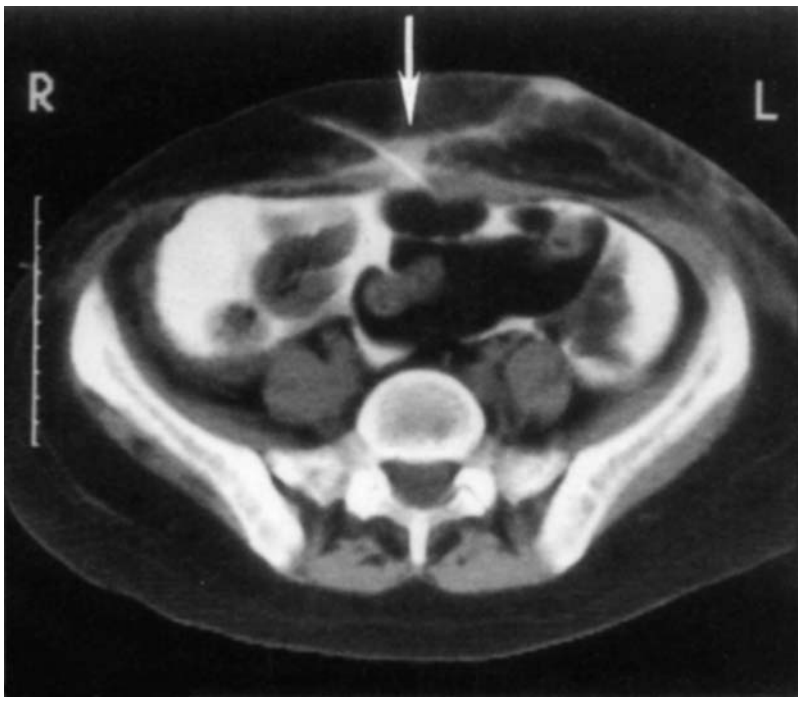

Fig. 14.44 Contrast-enhanced dialysate extravasating around the Tenckhoff catheter (arrow) implanted through the midline

image on T2 imaging due to the electrolyte content of the solution [360]. A potential risk of nephrogenic systemic fibrosis has been described with the intravenous administration of gadolinium in patients with kidney disease [362] but not with intraperitoneal administration so far. A retroperitoneal leak is demonstrated in Fig. 14.45.

Peritoneal scintigraphy is performed by adding 2–5 millicuries of technetium 99 m isotope to a bag of peritoneal dialysis solution [363, 365]. Multiple views in anterior-posterior, lateral, and oblique projections are taken to diagnose leaks and hernias. After completion of the procedure, the dialysate along with the instilled isotope is drained limiting the dose of radiation exposure [365]. Delayed scans are recommended in initially negative studies to diagnose small leaks [364].

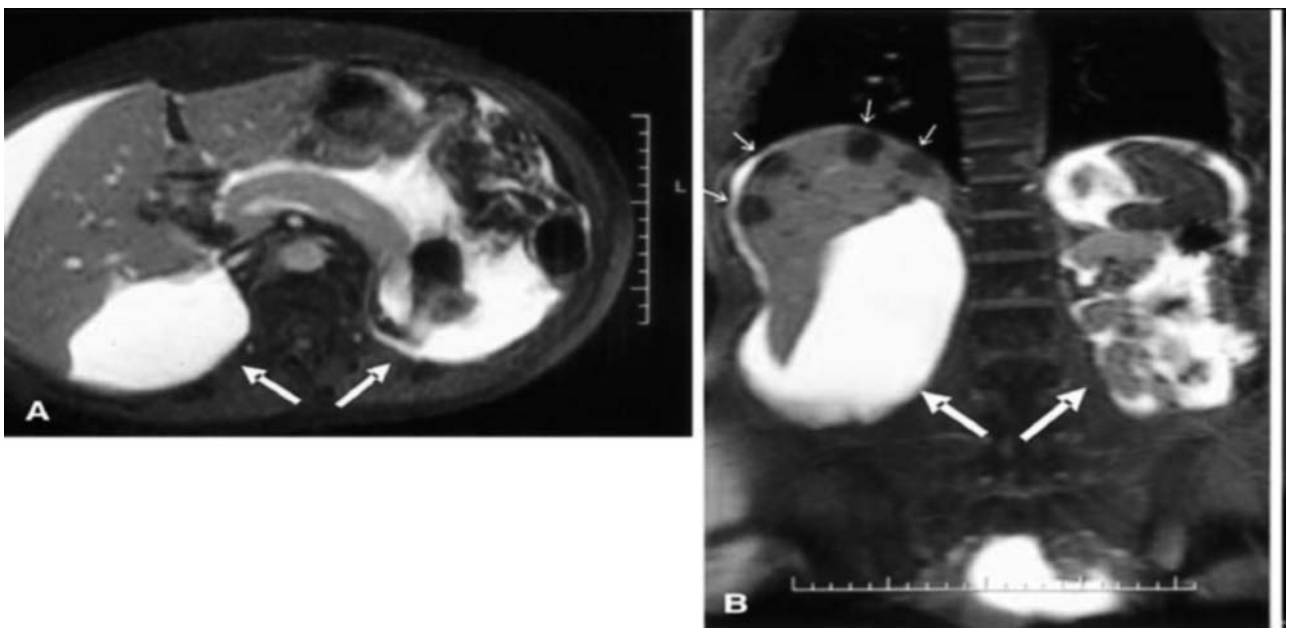

Fig. 14.45 Retroperitoneal fluid leak. (a) axial and (b) coronal T1-weighted images demonstrate retroperitoneal fluid leak (large arrows) in a patient who had bilateral nephrectomy secondary to polycystic kidney disease. Note multiple liver cysts (small arrows). With permission from Springer Science and Business Media [361]

An ultrasound is a good modality to assess the catheter tunnel. High resolution images can be obtained with a high frequency transducer. The intraperitoneal catheter is hard to visualize with ultrasound but Doppler interrogation while injecting saline may reveal the tip [292, 366, 367]. Due to the echogenicity of the catheter wall, acoustic shadows may hide fluid collections unless the tunnel is carefully examined from different angles. The ultrasound is an excellent modality to diagnose catheter tunnel and cuff infections [292, 367]. The normal catheter tunnel has a low-echo circumferential rim around the catheter and the cuff is seen as a cotton-like isoechoic area [366]. Tunnel infections cause a widening and loss of clarity of the circumferential area around the catheter. Abscesses may also be diagnosed on ultrasound and appear larger areas of decreased echotexture. Abscesses may be compressible and Doppler interrogation may show increased blood flow in the wall with no signal from the center of the pus collection [368]. Ultrasounds may also be used to follow response to therapy. This has been discussed in the section on exit-site infections.

Catheter Removal

Indications

The need for catheter removal occurs under various conditions. These may be broadly categorized under two headings: catheter malfunction and complicating medical conditions with a functioning catheter. Finally, the catheter may be removed electively because it is not needed.

Catheter Malfunction

The decision to remove the catheter is usually made only when conservative measures (described in the sections on early soft catheter complications and catheter obstruction, and in Table 14.10) to restore function have failed. Catheter malfunction requiring catheter removal may be seen in the following conditions: 1) intraluminal obstruction with blood or fibrin clot or omental tissue incarceration, 2) catheter tip migration out of the pelvis with poor drainage, 3) a catheter kink along its course, 4) catheter tip caught in adhesions, and 5) accidental break in the continuity of the catheter.

Functioning Catheter with a Complication

Under the following conditions catheters may have to removed: 1) recurrent peritonitis with no identifiable cause; 2) peritonitis due to exit-site and/or tunnel infection; 3) catheter with persistent exit-site infection; 4) tunnel infection and abscess; 5) late recurrent dialysate leak through the exit site or into the layers of the abdominal wall; 6) mycobacterial or fungal peritonitis; 7) bowel perforation with multiple organism peritonitis; 8) refractory peritonitis of other causes; 9) severe abdominal pain either due to catheter impinging on internal organs or during solution inflow; and 10) catheter cuff extrusion with infection.

Functioning Catheter That Is No Longer Needed

This situation is encountered after a successful renal transplantation or peritoneal dialysis is discontinued because dialysis is no longer needed, or the patient transfers to another form of dialysis.

Removal Methods

Uncuffed Catheter

Removal of the uncuffed catheter is a simple procedure. After cutting the anchoring suture the catheter is simply pulled out and the opening is covered with a sterile dressing.

Cuffed Catheters

A Tenckhoff catheter inserted through the midline may be removed at the bedside. After preparation of the operating field, local anesthesia is applied around the cuffs, the incisions are reopened, the cuffs are excised, and the catheter is pulled. The incisions of catheters removed for cuff/tunnel infection should be packed open and allowed to heal by

second intention. In our experience, calcium–sodium alginate fibers (Kaltostat Wound Dressing) are excellent for wound packing. The fibers absorb exudate very efficiently, control minor bleeding, and protect the wound from contamination. Once-daily dressing change is usually sufficient for wound packing with the fibers.

The catheters inserted through the belly of the rectus muscle require surgical dissection in the operating room to remove. Although the catheter can be removed using a local anesthetic, patient comfort usually dictates a general anesthetic, particularly for the Toronto Western Hospital, swan-neck abdominal Missouri, and presternal catheters. After an appropriate surgical scrub and routine draping the incision is reopened. The anterior rectus fascia is reopened along the site of the previous incision and the catheter/cuff/flange are sharply dissected free of the ingrown rectus muscle. The previously placed fixation sutures in the flange and the purse-string sutures are cut and, with traction and continued sharp dissection, the abdominal portion of the catheter is removed. Care must be taken to protect the underlying viscera. The remaining small opening into the abdomen is closed with O or OO Prolene® sutures. The anterior fascia is reapproximated in a similar fashion. Depending on the clinical indication for removal, the incision may either be closed or packed open and allowed to heal by second intention.

Swan-Neck Presternal Catheter

Removal of a swan-neck presternal peritoneal dialysis catheter is a surgical procedure performed in the operating room, preferably with general anesthesia. After an appropriate surgical scrub and routine draping of both the chest and abdomen, both the chest and abdominal incisions are reopened. Bleeding is controlled with electrocautery. Using blunt and sharp dissection, the two cuffs at the bent portion of the catheter are freed from the adjacent subcutaneous tissue. Working from the abdominal incision, the catheter is divided between sutures *above* the titanium connector. The chest portion of the catheter is pulled out in a cephalad direction through the chest (parasternal) incision. The abdominal part of the catheter is then removed in an identical way as described for the swan-neck Missouri abdominal and Toronto Western Hospital catheters. Depending on the clinical indication for removal the two incisions may either be closed or packed open and allowed to heal by second intention.

Operations in Peritoneal Dialysis Patients

Extra-Abdominal

A number of operative procedures may be carried out in the dialysis patient. The patients may undergo a variety of extra-abdominal operations such as coronary artery bypass, lower extremity revascularization, carotid endarterectomy, and, on occasion, the creation of a hemodialysis access. Prior to the operative procedure the dialysis fluid should be drained. Since the abdominal cavity has not been violated, dialysis may be started immediately following the patient's return to the surgical floor. Special caution is required in patients who have presternal catheters. Patients undergoing coronary artery bypass surgery or thoracotomy require particular attention to the location of the presternal catheter to avoid damage to the catheter. Peritoneal dialysis may be restarted on the day of surgery in the supine position in these patients.

Abdominal

A whole series of abdominal operations may be contemplated and carried out in patients on chronic ambulatory peritoneal dialysis. The operations range from cholecystectomy to colectomy to hernia repairs. Operations on the abdominal wall carry less risk to the patient from the standpoint of developing peritonitis or catheter loss. These operations include all abdominal wall hernias and they can be carried out with some ease and a high degree of safety.

Intra-abdominal procedures on the intestine or the gallbladder for acute or chronic disease may predispose to a risk of infection or loss of the catheter secondary to infectious complications. Procedures such as laparoscopic cholecystectomy can be carried out with minimal risk of spillage of bile or contaminated contents, and after rinsing the abdominal cavity the catheter can be rested and dialysis begun in a few weeks time. In the case of a perforated viscus such as a perforated sigmoid diverticulum or a perforated peptic ulcer with peritoneal soilage the catheter will undoubtedly be lost at that setting. It is safer to remove the peritoneal catheter with massive abdominal soilage because the presence of a foreign body will often prolong or potentiate the risk of persisting infection. Once the patient

is recovered from the acute intra-abdominal process consideration can be given to restarting peritoneal dialysis. Depending upon the extent of peritonitis and intra-abdominal adhesion formation, peritoneal dialysis may or may not be possible.

In general, prior to abdominal procedures the abdomen should be drained prior to operation. In our institution we use a first-generation cephalosporin as a prophylactic antibiotic for elective operations and therapeutic antibiotics based on culture for operations associated with significant intra-abdominal soilage. As mentioned, those patients having significant intra-abdominal peritonitis are better served by removal of their catheter at the time of their initial operation with a re-establishment of peritoneal dialysis at a future date. After an elective operation such as cholecystectomy, in-and-out exchanges in the supine position are started immediately after the patient reaches the floor. We limit the volume of exchanges to 1 L and heparin 1,000 units per liter are added to the fluid. These exchanges continue until the dialysate is clear. Ceftazidime 500 mg is added to the last exchange and that exchange is not drained. Metronidazole 500 mg *per os*/intravenous/rectal is used for 5 days following elective procedures. The day following the operation, in-and-out exchanges are repeated until the dialysate is clear and again 500 mg of ceftazidime is added to the last exchange, which is not drained for 12 h.

To prevent incisional hernia/leak ambulatory peritoneal dialysis is delayed for 2–6 weeks depending upon the type of operation and the general condition of the patient. Collagen maturation is slower in diabetic, immunosuppressed, and undernourished patients. Restart of peritoneal dialysis should be delayed in such patients.

Concluding Remarks

Peritoneal catheters are lifelines for peritoneal dialysis patients. While advances in catheter placement and subsequent care have made it possible to obtain and maintain access to the peritoneal cavity safely over an extended period of time, catheter-related complications remain responsible for over 20% transfers out of peritoneal dialysis. Meticulous care starting prior to catheter insertion with choosing the site of insertion, appropriate surgical techniques, and subsequent care are essential to the success of peritoneal access. Complications must be addressed early to save the catheter and the peritoneum complimented by the use of appropriate imaging techniques. Further research and innovation will form the basis of future improvements in outcomes.

REFERENCES

1. Flanigan M, Gokal R: Peritoneal catheters and exit-site practices toward optimum peritoneal access: a review of current developments. *Perit Dial Int* 25:132–139, 2005
2. Twardowski Z: Peritoneal dialysis glossary II. *Perit Dial Int* 8:15–77, 1988
3. Twardowski ZJ, Nichols WK, Nolph KD, *et al*.: Swan neck presternal ("bath tub") catheter for peritoneal dialysis. *Adv Perit Dial* 8:316–324, 1992
4. Twardowski ZJ: History of peritoneal access development. *Int J Artif Organs* 29:2–40, 2006
5. Ganter G: Ueber die Beseitigung giftiger Stoffe aus dem Blute durch Dialyse (On the elimination of toxic substances from the blood by dialysis). *Münch Med Wschr* 70:1478–1480, 1923
6. Landsberg M, Gnoinski H: Recherches sur la diffusion de l'urée dans le péritoine sur le vivant (Research of the urea diffusion through the peritoneum in vivo). *Compt Rend Soc Biol* 93:787–788, 1925
7. Rosenak S, Siwon P: Experimentelle Untersuchungen über die peritoneale Ausscheidung harnpflichtiger Substanzen aus dem Blute (Experimental investigations on the peritoneal elimination from the blood of substances normally excreted in urine). *Mitt a d Grenzgeb d Med u Chir* 39:391–408, 1926
8. Heusser H, Werder H: Untersuchungen über Peritonealdialyse (Investigations on peritoneal dialysis). *Beitr z Klin Chir* 41:38–49, 1927
9. Balázs J, Rosenak S: Zur Behandlung der Sublimatanurie durch peritoneale Dialyse (On the treatment of anuria caused by mercury bichloride with peritoneal dialysis). *Wien Klin Wchschr* 47:851–854, 1934
10. Wear J, Sisk I, Trinkle A: Peritoneal lavage in the treatment of uremia. *J Urol* 39:53–62, 1938
11. Rhoads JE: Peritoneal lavage in the treatment of renal insufficiency. *Am J Med Sci* 196:642–647, 1938
12. Abbott WE, Shea P: The treatment of temporary renal insufficiency (uremia) by peritoneal lavage. *Am J Med Sci* 211:312–319, 1946
13. Seligman AM, Frank HA, Fine J: Treatment of Experimental Uremia by Means of Peritoneal Irrigation. *J Clin Invest* 25:211–219, 1946
14. Fine J, Frank H, Seligman A: The treatment of acute renal failure by peritoneal irrigation. *Ann Surg* 124:857–878, 1946
15. Frank H, Seligman A, Fine J: Treatment of uremia after acute renal failure by peritoneal irrigation. *JAMA* 130:703–705, 1946
16. Weiss HA, Mills RL: Treatment of uremia with continuous peritoneal irrigation. *U.S. Nav Med Bull* 46:1745–1750, 1946
17. Reid R, Penfold J, Jones R: Anuria treated by renal decapsulation and peritoneal dialysis. *Lancet* CCLI:749–753, 1946
18. Rosenak S, Oppenheimer G: An improved drain for peritoneal lavage. *Surgery* 23:832–833, 1948
19. Odel H, Ferris D, Power M: Clinical consideration of problem of extrarenal excretion: Peritoneal lavage. *Med Clin North America* 32:989–1076, 1948

20. Ferris D, Odel H: An improved plastic tube for use in peritoneal lavage: Preliminary report. *Proc Staff Meet Mayo Clinic* 23:612–614, 1948
21. Frank H, Seligman A, Fine J, *et al*.: Further experiences with peritoneal irrigation for acute renal failure. *Ann Surg* 128:561–608, 1948
22. Dérot M, Tanret P, Roussilon J, *et al*.: La dialyse péritonéale dans le traitement de l'urémie aiguë. (Peritoneal dialysis in the treatment of acute uremia) *J d'Urol* 55:113–121, 1949
23. Grollman A, Turner LB, Mc LJ: Intermittent peritoneal lavage in nephrectomized dogs and its application to the human being. *AMA Arch Intern Med* 87:379–390, 1951
24. Grollman A, Turner LB, Levitch M, *et al*.: Hemodynamics of bilaterally nephrectomized dog subjected to intermittent peritoneal lavage. *Am J Physiol* 165:167–172, 1951
25. Maxwell MH, Rockney RE, Kleeman CR, *et al*.: Peritoneal dialysis. 1. Technique and applications. *J Am Med Assoc* 170:917–924, 1959
26. Doolan PD, Murphy WP, Jr., Wiggins RA, *et al*.: An evaluation of intermittent peritoneal lavage. *Am J Med* 26:831–844, 1959
27. Boen ST, Mion CM, Curtis FK, *et al*.: Periodic peritoneal dialysis using the repeated puncture technique and an automatic cycling machine. *Trans Am Soc Artif Intern Organs* 10:409–414, 1964
28. McDonald H: A peritoneal dialysis trocar. *J Urol* 89:946–947, 1963
29. Weston RE, Roberts M: Clinical Use of Stylet-Catheter for Peritoneal Dialysis. *Arch Intern Med* 115:659–662, 1965
30. Gutch CF: Peritoneal dialysis. *Trans Am Soc Artif Intern Organs* 10:406–408, 1964
31. Palmer RA, Quinton WE, Gray JE: Prolonged Peritoneal Dialysis for Chronic Renal Failure. *Lancet* 1:700–702, 1964
32. Tenckhoff H, Shilipetar G, Boen ST: One Year's Experience with Home Peritoneal Dialysis. *Trans Am Soc Artif Intern Organs* 11:11–17, 1965
33. McDonald HP, Jr., Gerber N, Mishra D, *et al*.: Subcutaneous dacron and teflon cloth adjuncts for silastic arteriovenous shunts and peritoneal dialysis catheters. *Trans Am Soc Artif Intern Organs* 14:176–180, 1968
34. Tenckhoff H, Schechter H: A bacteriologically safe peritoneal access device. *Trans Am Soc Artif Intern Organs* 14:181–187, 1968
35. Stephen RL, Atkin-Thor E, Kolff WJ: Recirculating peritoneal dialysis with subcutaneous catheter. *Trans Am Soc Artif Intern Organs* 22:575–585, 1976
36. Gotloib L, Galili N, Nisencorn I, *et al*.: Subcutaneous intraperitoneal prosthesis for maintenance peritoneal dialysis. *Lancet* 1:1318–1319, 1975
37. Bay WH, Vaccaro PS, Powell SL, *et al*.: The Gore-Tex peritoneal catheter: a clinical evaluation and comparison with the Tenckhoff catheter. *Am J Kidney Dis* 4:268–279, 1984
38. Ogden DA, Benavente G, Wheeler D, *et al*.: Experience with the right angle Gore-Tex® peritoneal dialysis catheter, in *Advances in Continuous Ambulatory Peritoneal Dialysis: Selected papers from the Sixth Annual CAPD Conference* edited by Khanna R, Nolph KD, Prowant BF, Twardowski ZJ, Oreopoulos DG, Kansas City, Missouri, Peritoneal Dialysis Bulletin, Inc, 1986, pp 155–159
39. Goldberg EM, Hill W: A new peritoneal access prosthesis. *Proc Clin Dial Transplant Forum* 3:122–125, 1973
40. Oreopoulos DG, Izatt S, Zellerman G, *et al*.: A prospective study of the effectiveness of three permanent peritoneal catheters. *Proc Clin Dial Transplant Forum* 6:96–100, 1976
41. Valli A, Comotti C, Torelli D, *et al*.: A new catheter for peritoneal dialysis (two years of experience with Valli catheter). *Trans Am Soc Artif Intern Organs* 29:629–632, 1983
42. Valli A, Andreotti C, Degetto Pea: 48-months' experience with Valli-2 catheter, in *Eighth Annual CAPD Conference* (vol 4), edited by Khanna R, Nolph KD, Prowant BF, Twardowski ZJ, Oreopoulos DG, Kansas City, Missouri, Toronto: Peritoneal Dialysis Bulletin, Inc., 1988, pp 292–297.
43. Thornhill JA, Dhein CR, Johnson H, *et al*.: Drainage characteristics of the column disc catheter: a new chronic peritoneal access catheter. *Proc Clin Dial Transplant Forum* 10:119–125, 1980
44. Shah GM, Sabo A, Nguyen T, *et al*.: Peritoneal catheters: a comparative study of column disc and Tenckhoff catheters. *Int J Artif Organs* 13:267–272, 1990
45. Ash SR, Janle EM: T-fluted peritoneal dialysis catheter. *Adv Perit Dial* 9:223–226, 1993
46. Chiaramonte S, Feriani M, Biasoli S, *et al*.: Clinical experience with short peritoneal dialysis catheters. *Proc Eur Dial Transplant Assoc Eur Ren Assoc* 22:426–430, 1985
47. Chiaramonte S, Bragantini L, Brendolan A, *et al*.: Long-term experience with the Vicenza catheter, in *Proceedings of the Fifth Congress of the International Society for Peritoneal Dialysis* edited by Ota K, Maher J, Winchester J, Hirszel P, Ito K, Suzuki T, Kyoto 1990, Excerpta Medica, Amsterdam-London-New York-Tokyo. Elsevier Science Publishers B.V. 1992, pp 160–163
48. Di Paolo N, Petrini G, Garosi G, *et al*.: A new self-locating peritoneal catheter. *Perit Dial Int* 16:623–627, 1996
49. Ponce S, Pierratos A, Izatt S, *et al*.: Comparison of the survival and complications of three permanent peritoneal dialysis catheters. *Perit Dial Bull* 2:82–86, 1982
50. Twardowski Z, Nolph K, Khanna R, *et al*.: The need for a "Swan Neck" permanently bent, arcuate peritoneal dialysis catheter. *Perit Dial Bull* 5:219–223, 1985
51. Cruz C: Clinical experiencce with a new peritoneal access device (the Cruz™ catheter), in *Proceedings of the Fifth Congress of the International Society for Peritoneal Dialysis* edited by Ota K, Maher J, Winchester J, Hirszel P, Ito K, Suzuki T, Kyoto 1990, Excerpta Medica, Amsterdam, London, New York, Tokyo 1992, pp 164–169
52. Twardowski ZJ: Presternal peritoneal catheter. *Adv Ren Replace Ther* 9:125–132, 2002
53. Moncrief JW, Popovich RP, Broadrick LJ, *et al*.: The Moncrief-Popovich catheter. A new peritoneal access technique for patients on peritoneal dialysis. *Asaio J* 39:62–65, 1993
54. Boen S: Peritoneal Dialysis: A clinical study of factors governing its effectiveness, in *Te Assen Bij van Gorcum & Comp, NV* (vol MD), University of Amsterdam, 1959
55. Lange K, Treser G, Mangalat J: Automatic continuous high flow rate peritoneal dialysis. *Arch Klin Med* 214:201–206, 1968
56. Twardowski Z: New approaches to intermittent peritoneal dialysis therapies, in *Peritoneal Dialysis*, edited by Nolph K, Third edition ed, Kluwer Academic Publishers, Dordrecht/Boston/London 1989, 1989, pp 133–151
57. Diaz-Buxo JA: Streaming, mixing, and recirculation: role of the peritoneal access in continuous flow peritoneal dialysis (clinical considerations). *Adv Perit Dial* 18:87–90, 2002

58. Diaz-Buxo JA: Continuous-flow peritoneal dialysis: update. *Adv Perit Dial* 20:18–22, 2004
59. Ronco C, Wentling AG, Amerling R, *et al.*: New catheter design for continuous flow peritoneal dialysis. *Contrib Nephrol* 142:447–461, 2004
60. Kathuria P, Moore HL, Mehrotra R, *et al.*: Evaluation of healing and external tunnel histology of silver-coated peritoneal catheters in rats. *Adv Perit Dial* 12:203–208, 1996
61. Kathuria P, Moore HL, Prowant BF, *et al.*: Preliminary evaluation of silver-coated peritoneal catheters in rats. *Adv Perit Dial* 11:189–192, 1995
62. Crabtree JH, Burchette RJ, Siddiqi RA, *et al.*: The efficacy of silver-ion implanted catheters in reducing peritoneal dialysis-related infections. *Perit Dial Int* 23:368–374, 2003
63. Guggenbichler JP, Boswald M, Lugauer S, *et al.*: A new technology of microdispersed silver in polyurethane induces antimicrobial activity in central venous catheters. *Infection* 27 Suppl 1:S16–23, 1999
64. Boswald M, Girisch M, Greil J, *et al.*: Antimicrobial activity and biocompatibility of polyurethane and silicone catheters containing low concentrations of silver: a new perspective in prevention of polymer-associated foreign-body-infections. *Zentralbl Bakteriol* 283:187–200, 1995
65. Kalfon P, de Vaumas C, Samba D, *et al.*: Comparison of silver-impregnated with standard multi-lumen central venous catheters in critically ill patients. *Crit Care Med* 35:1032–1039, 2007
66. Khare MD, Bukhari SS, Swann A, *et al.*: Reduction of catheter-related colonisation by the use of a silver zeolite-impregnated central vascular catheter in adult critical care. *J Infect* 54:146–150, 2007
67. Kahl AA, Grosse-Siestrup C, Kahl KA, *et al.*: Reduction of exit-site infections in peritoneal dialysis by local application of metallic silver: a preliminary report. *Perit Dial Int* 14:177–180, 1994
68. Pommer W, Brauner M, Westphale HJ, *et al.*: Effect of a silver device in preventing catheter-related infections in peritoneal dialysis patients: silver ring prophylaxis at the catheter exit study. *Am J Kidney Dis* 32:752–760, 1998
69. Twardowski ZJ, Prowant BF: Exit-site healing post catheter implantation. *Perit Dial Int* 16 Suppl 3:S51–S70, 1996
70. Hanna H, Bahna P, Reitzel R, *et al.*: Comparative in vitro efficacies and antimicrobial durabilities of novel antimicrobial central venous catheters. *Antimicrob Agents Chemother* 50:3283–3288, 2006
71. McConnell SA, Gubbins PO, Anaissie EJ: Do antimicrobial-impregnated central venous catheters prevent catheter-related bloodstream infection? *Clin Infect Dis* 37:65–72, 2003
72. Falagas ME, Fragoulis K, Bliziotis IA, *et al.*: Rifampicin-impregnated central venous catheters: a meta-analysis of randomized controlled trials. *J Antimicrob Chemother* 59:359–369, 2007
73. Kim CY, Kumar A, Sampath L, *et al.*: Evaluation of an antimicrobial-impregnated continuous ambulatory peritoneal dialysis catheter for infection control in rats. *Am J Kidney Dis* 39:165–173, 2002
74. Trooskin SZ, Donetz AP, Baxter J, *et al.*: Infection-resistant continuous peritoneal dialysis catheters. *Nephron* 46:263–267, 1987
75. Trooskin SZ, Harvey RA, Lennard TW, *et al.*: Failure of demonstrated clinical efficacy of antibiotic-bonded continuous ambulatory peritoneal dialysis (CAPD) catheters. *Perit Dial Int* 10:57–59, 1990
76. Amano I, Katoh T, Inagaki Y: Development of alumina ceramic transcutaneous connector to prevent skin exit site infections around CAPD catheters. *ASAIO Trans* 36:M494–496, 1990
77. Negoi D, Prowant BF, Twardowski ZJ: Current trends in the use of peritoneal dialysis catheters. *Adv Perit Dial* 22:147–152, 2006
78. Twardowski ZJ, Nolph KD, Khanna R, *et al.*: Computer interaction: catheters. *Adv Perit Dial* 10:11–18, 1994
79. Gadallah MF, Mignone J, Torres C, *et al.*: The role of peritoneal dialysis catheter configuration in preventing catheter tip migration. *Adv Perit Dial* 16:47–50, 2000
80. Twardowski ZJ, Nolph KD, Khanna R, *et al.*: The need for a 'Swan Neck' permanently bent, arcuate peritoneal dialysis catheter. *Perit Dial Bull* 5:219–223, 1985
81. Twardowski ZJ, Khanna R, Nolph KD, *et al.*: Preliminary experience with the Swan Neck peritoneal dialysis catheters. *ASAIO Trans* 32:64–67, 1986
82. Twardowski ZJ, Prowant BF, Khanna R, *et al.*: Long-term experience with Swan Neck Missouri catheters. *ASAIO Trans* 36:M491–494, 1990
83. Twardowski ZJ, Prowant BF, Nichols WK, *et al.*: Six-year experience with swan neck catheters. *Perit Dial Int* 12:384–389, 1992
84. Twardowski ZJ, Nichols WK, Khanna R, *et al.*: Swan neck Missouri peritoneal dialysis catheters: design, insertion, and break-in. Video produced by the Academic Support Center, University of Missouri, Columbia, MO, USA. 1993
85. Twardowski ZJ, Prowant BF, Pickett B, *et al.*: Four-year experience with swan neck presternal peritoneal dialysis catheter. *Am J Kidney Dis* 27:99–105, 1996
86. Twardowski ZJ, Nichols WK, Nolph KD, *et al.*: Swan neck presternal peritoneal dialysis catheter. *Perit Dial Int* 13 Suppl 2:S130–132, 1993
87. Sieniawska M, Roszkowska-Blaim M, Warchol S: Swan neck presternal catheter for continuous ambulatory peritoneal dialysis in children. *Pediatr Nephrol* 7:557–558, 1993
88. Cruz C: Cruz catheter: implantation technique and clinical results. *Perit Dial Int* 14 Suppl 3:S59–62, 1994
89. Tenckhoff H: Home peritoneal dialysis, in *Clinical Aspects of Uremia and Dialysis*, edited by Massry SG, Sellers AL, Spring-field: Charles C Thomas, 1976, pp 583–615
90. Twardowski ZJ, Nichols WK, Khanna R, *et al.*: Swan neck presternal peritoneal dialysis catheter: design, insertion, and break-in. Video produced by the Academic Support Center, University of Missouri, Columbia, MO, U.S.A., 1993
91. Ash SR, Daugirdas JT: Peritoneal Access devices, in *Handbook of Dialysis*, edited by Daugirdas JT, Ing TS, Boston, Little Brown, 1994, pp 275–300.
92. Ash SR, Nichols WK: Placement, repair, and removal of chronic peritoneal catheters, in *Textbook of Peritoneal Dialysis*, edited by Gokal R, Nolph KD, Dordrecht, Kluwer, 1994, pp 315–333
93. Zappacosta AR: Seldinger technique for placement of the Tenckhoff catheter. Video produced by the Bryn Mawr Hospital. 1984
94. Zappacosta AR, Perras ST, Closkey GM: Seldinger technique for Tenckhoff catheter placement. *ASAIO Trans* 37:13–15, 1991

95. Gonzales AR, Goltz GM, Eaton CL, *et al*.: The peel away method for insertion of Tenckhoff catheter. *Am Soc Nephrol* 16:119A (abstract), 1983
96. Updike S, O'Brien M, Peterson W, *et al*.: Placement of catheter using pacemaker-like introducer with peel-away sleeve *Am Soc Nephrol* 17:87A (abstract), 1984
97. Twardowski ZJ, Khanna R, Nolph KD, *et al*.: Peritoneal dialysis catheter: principles of design, implantation, and early care. *Video produced by the Academic Support Center*, *University of Missouri*, *Columbia, MO, USA*, 1993
98. Schmidt LM, Craig PS, Prowant BF, *et al*.: A simple method of preventing accidental disconnection at the peritoneal catheter adapter junction. *Perit Dial Int* 10:309–310, 1990
99. Valk TW, Swartz RD, Hsu CH: Peritoneal dialysis in acute renal failure: analysis of outcome and complications *Dial Transplant* 9:48–54, 1980
100. Vaamonde CA, Michael UF, Metzger RA, *et al*.: Complications of acute peritoneal dialysis. *J Chronic Dis* 28:637–659, 1975
101. Maher JF, Schreiner GE: Hazards and complications of dialysis. *N Engl J Med* 273:370–377, 1965
102. Rudnick MR, Coyle JF, Beck H, *et al*.: Acute massive hydrothorax complicating peritoneal dialysis, report of 2 cases and a review of the literature. . *Clin Nephrol* 12:38–44, 1980
103. Firmat J, Zucchini A: Peritoneal dialysis in acute renal failure. *Contrib Nephrol* 17:33–38, 1979
104. Edwards SR, Unger AM: Acute hydrothorax—a new complication of peritoneal dialysis. *Jama* 199:853–855, 1967
105. Finn R, Jowett EW: Acute hydrothorax complicating peritoneal dialysis. *Br Med J* 2:94, 1970
106. Holm J, Lieden B, Lindqvist B: Unilateral pleural effusion–a rare complication of peritoneal dialysis. *Scand J Urol Nephrol* 5:84–85, 1971
107. Haberli R, Stucki P: [Acute hydrothorax as complication of peritoneal dialysis]. *Schweiz Rundsch Med Prax* 60:13–14, 1971
108. Alquier P, Achard J, Bonhomme R: [Letter: Acute hydrothorax during peritoneal dialysis. A propos of 5 cases]. *Nouv Presse Med* 4:192, 1975
109. Fehmirling E, Christensen E: Hydrothorax under peritoneal-dialyse. *Ugeskr Laeg* 137:1650–1651, 1975
110. Ribot S, Jacobs MG, Frankel HJ, *et al*.: Complications of peritoneal dialysis. *Am J Med Sci* 252:505–517, 1966
111. Mion CM, Boen ST: Analysis of factors responsible for the formation of adhesions during chronic peritoneal dialysis. *Am J Med Sci* 250:675–679, 1965
112. Matalon R, Levine S, Eisinger RP: Hazards in routine use of peritoneal dialysis. *N Y State J Med* 71:219–224, 1971
113. Henderson LW: Peritoneal dialysis, in *Clinical Aspects of Uraemia and Dialysis*, edited by Massry SG, Sellers AL, Spring-field: Charles C. Thomas, 1976, p 574
114. Chugh KS, Bhattacharya K, Amaresan MS, *et al*.: Peritoneal dialysis–our experience based on 550 dialyses. *J Assoc Physicians India* 20:215–221, 1972
115. Nienhuis LI: Clinical peritoneal dialysis. *Arch Surg* 93:643–653, 1966
116. Pauli HG, Buttikofer E, Vorburger C: Clinical experience with peritoneal dialysis. *Helv Med Acta* 33:51–58, 1966
117. Denovales EL, Avendano LN: Risks of peritoneal catheter insertion (letter). *Lancet* 1:473, 1968
118. Dunea G: Peritoneal dialysis and hemodialysis. *Med Clin North Am* 55:155–175, 1971
119. Passadakis PS, Oreopoulos DG: Peritoneal dialysis in patients with acute renal failure. *Adv Perit Dial* 23:7–16, 2007
120. Chitalia VC, Almeida AF, Rai H, *et al*.: Is peritoneal dialysis adequate for hypercatabolic acute renal failure in developing countries? *Kidney Int* 61:747–757, 2002
121. Krebs RA, Burtis BB: Bowel perforation. A complication of peritoneal dialysis using a permanent peritoneal cannula. *JAMA* 198:486–487, 1966
122. Simkin EP, Wright FK: Perforating injuries of the bowel complicating peritoneal catheter insertion. *Lancet* 1:64–66, 1968
123. Rigolosi RS, Maher JF, Schreiner GE: Intestinal perforation during peritoneal dialysis. *Ann Intern Med* 70:1013–1015, 1969
124. Rao P, Passadakis P, Oreopoulos DG: Peritoneal dialysis in acute renal failure. *Perit Dial Int* 23:320–322, 2003
125. Phu NH, Hien TT, Mai NT, *et al*.: Hemofiltration and peritoneal dialysis in infection-associated acute renal failure in Vietnam. *N Engl J Med* 347:895–902, 2002
126. Smith EK, Chamberlain MJ: Complication of Peritoneal Dialysis. *Br Med J* 1:126–127, 1965
127. Goldsmith HJ, Edwards EC, Moorhead PJ, *et al*.: Difficulties encountered in intermittent dialysis for chronic renal failure. *Br J Urol* 38:625–634, 1966
128. Stein MF, Jr.: Intraperitoneal loss of a dialysis catheter. *Ann Intern Med* 71:869–870, 1969
129. Gokal R, Alexander S, Ash S, *et al*.: Peritoneal catheters and exit-site practices toward optimum peritoneal access: 1998 update. (Official report from the International Society for Peritoneal Dialysis). *Perit Dial Int* 18:11–33, 1998
130. Oreopoulos DG, Helfrich GB, Khanna R: Peritoneal dialysis catheter implantation. Video developed by Baxter's Catheter and Exit Site Advisory Committee, Baxter Healthcare Corporation. 1988
131. Poirier V, Daly B, Dasse K, *et al*.: Elimination of tunnel infection, in *Frontiers in Peritoneal Dialysis. Proceedings of the III International Symposium on Peritoneal Dialysis*, edited by Maher J, Winchester J, Washington, D.C., 1984 New York: Field, Rich, 1986, pp 210–217
132. Ash S: Y-TEC peritoneoscopic implantation of the peritoneal dialysis catheter. *Video produced by Medigroup Inc*., *North Aurora, IL, USA*, 1993
133. Copley JB, Lindberg JS, Back SN, *et al*.: Peritoneoscopic placement of Swan neck peritoneal dialysis catheters. *Perit Dial Int* 16 Suppl 1:S330–332, 1996
134. Updike S, Zimmerman S, O'Brien M, *et al*.: Peel-Away® sheath technique for placing peritoneal dialysis catheters. *Video produced by Television Studio, School of Nursing, Univerity of Wisconsin*, *Madison, WI, USA*, 1984
135. Twardowski ZJ, Khanna R: Swan neck peritoneal dialysis catheter, in *Vascular and Peritoneal Access for Dialysis*, edited by Andreucci VE, Boston, Kluwer, 1989, pp 271–289
136. Dasgupta MK: Moncrief-Popovich catheter and implantation technique: the AV fistula of peritoneal dialysis. *Adv Ren Replace Ther* 9:116–124, 2002
137. Crabtree JH: Selected best demonstrated practices in peritoneal dialysis access. *Kidney Int Suppl* 70:S27–37, 2006

138. Moncrief JW, Popovich RP, Dasgupta M, *et al*.: Reduction in peritonitis incidence in continuous ambulatory peritoneal dialysis with a new catheter and implantation technique. *Perit Dial Int* 13 Suppl 2:S329–331, 1993
139. Danielsson A, Blohme L, Tranaeus A, *et al*.: A prospective randomized study of the effect of a subcutaneously "buried" peritoneal dialysis catheter technique versus standard technique on the incidence of peritonitis and exit-site infection. *Perit Dial Int* 22:211–219, 2002
140. Prischl FC, Wallner M, Kalchmair H, *et al*.: Initial subcutaneous embedding of the peritoneal dialysis catheter–a critical appraisal of this new implantation technique. *Nephrol Dial Transplant* 12:1661–1667, 1997
141. Moncrief–Popovich catheter. A video produced by Austin Biomedical Research Institute A, TX, USA., 1991
142. Adamson AS. K, J. P., Snell, M. E., Hulme, B.: Endoscopic placement of CAPD catheters: a review of one hundred procedures. *Nephrol Dial Transplant* 7:855–857, 1992
143. Al-Dohayan A: Laparoscopic placement of peritoneal dialysis catheter (same day dialysis). *Jsls* 3:327–329, 1999
144. Amerling R, Cruz C: A new laparoscopic method for implantation of peritoneal catheters. *Asaio J* 39:M787–789, 1993
145. Blessing WD, Jr., Ross JM, Kennedy CI, *et al*.: Laparoscopic-assisted peritoneal dialysis catheter placement, an improvement on the single trocar technique. *Am Surg* 71:1042–1046, 2005
146. Brownlee J, Elkhairi S: Laparoscopic assisted placement of peritoneal dialysis catheter: a preliminary experience. *Clin Nephrol* 47:122–124, 1997
147. Dalgic A, Ersoy E, Anderson ME, *et al*.: A novel minimally invasive technique for insertion of peritoneal dialysis catheter. *Surg Laparosc Endosc Percutan Tech* 12:252–254, 2002
148. Draganic B, James A, Booth M, *et al*.: Comparative experience of a simple technique for laparoscopic chronic ambulatory peritoneal dialysis catheter placement. *Aust N Z J Surg* 68:735–739, 1998
149. Leung LC, Yiu MK, Man CW, *et al*.: Laparoscopic management of Tenchkoff catheters in continuous ambulatory peritoneal dialysis. A one-port technique. *Surg Endosc* 12:891–893, 1998
150. Ogunc G: A new laparoscopic technique for CAPD catheter placement. *Perit Dial Int* 19:493–494, 1999
151. Soontrapornchai P, Simapatanapong T: Comparison of open and laparoscopic secure placement of peritoneal dialysis catheters. *Surg Endosc* 19:137–139, 2005
152. Tsimoyiannis EC, Siakas P, Glantzounis G, *et al*.: Laparoscopic placement of the Tenckhoff catheter for peritoneal dialysis. *Surg Laparosc Endosc Percutan Tech* 10:218–221, 2000
153. Nijhuis PH, Smulders JF, Jakimowicz JJ: Laparoscopic introduction of a continuous ambulatory peritoneal dialysis (capd) catheter by a two-puncture technique. *Surg Endosc* 10:676–679, 1996
154. Crabtree JH, Fishman A: Videolaparoscopic implantation of long-term peritoneal dialysis catheters. *Surg Endosc* 13:186–190, 1999
155. Ogunc G: Malfunctioning peritoneal dialysis catheter and accompanying surgical pathology repaired by laparoscopic surgery. *Perit Dial Int* 22:454–462, 2002
156. Ogunc G: Minilaparoscopic extraperitoneal tunneling with omentopexy: a new technique for CAPD catheter placement. *Perit Dial Int* 25:551–555, 2005
157. Ogunc G, Tuncer M, Ogunc D, *et al*.: Laparoscopic omental fixation technique versus open surgical placement of peritoneal dialysis catheters. *Surg Endosc* 17:1749–1755, 2003
158. Caliskan K, Nursal TZ, Tarim AM, *et al*.: The adequacy of laparoscopy for continuous ambulatory peritoneal dialysis procedures. *Transplant Proc* 39:1359–1361, 2007
159. Misra M, Khanna R, Nichols WK: An unusual intraperitoneal repair of a peritoneal dialysis catheter. *Perit Dial Int* 18:339–341, 1998
160. Leblanc M, Ouimet D, Pichette V: Dialysate leaks in peritoneal dialysis. *Semin Dial* 14:50–54, 2001
161. Werner S, Grose R: Regulation of wound healing by growth factors and cytokines. *Physiol Rev* 83:835–870, 2003
162. Hall CW, Adams LM, Ghidoni JJ: Development of skin interfacing cannula. *Trans Am Soc Artif Intern Organs* 21:281–288, 1975
163. Kantrowitz A, Freed PS, Ciarkowski AA, *et al*.: Development of a percutaneous access device. *Trans Am Soc Artif Intern Organs* 26:444–449, 1980
164. Yaffe A, Shoshan S: Cessation of epithelial cell movement at native type I collagen-epithelial interface in vitro. *Coll Relat Res* 5:533–540, 1985
165. Winter GD: Transcutaneous implants: reactions of the skin-implant interface. *J Biomed Mater Res* 8:99–113, 1974
166. Gerritsen M, Paquay YG, Jansen JA: Evaluation of the tissue reaction to a percutaneous access device using titanium fibre mesh anchorage in goats. *J Mater Sci Mater Med* 9:523–528, 1998
167. Bar-Lev A, Freed PS, Mandell G: Long-term percutaneous device. *Perit Dial Bull*:81–87, 1987
168. Winter GD: Epidermal regeneration studied in the domestic pig, in *Epidermal Wound Healing*, edited by Maibach H, Rovee D, Chicago, Year Book Medical, 1972, pp 71–112
169. Winter GD: Movement of epidermal cells over the wound surface, in *Advances in Biology of Skin, Vol. 5: Wound Healing*, edited by Montagna W, Billingham R, Oxford, Pergamon Press, 1964, pp 113–127
170. Krawczyk W: Some ultrastructural aspects of epidermal repair in two model wound healing systems, in *Epidermal Wound Healing*, edited by Maibach H, Rovee D, Chicago, Year Book Medical, 1972, pp 123–131
171. Dasse KA, Daly BDT, Bousquet G, *et al*.: A polyurethane percutaneous access device for peritoneal dialysis, in *Advances in Continuous Ambulatory Peritoneal Dialysis. Selected papers from the Eighth Annual CAPD Conference, Kansas City, Missouri, February 1988*, edited by Khanna R, Nolph KD, Prowant BF, Twardowski ZJ, Oreopoulos GD, Toronto, Peritoneal Dialysis Bulletin, Inc, 1988, pp 245–252
172. Daly BD, Dasse KA, Haudenschild CC, *et al*.: Percutaneous energy transmission systems: long-term survival. *Trans Am Soc Artif Intern Organs* 29:526–531, 1983
173. Khanna R, Twardowski ZJ: Peritoneal catheter exit site. *Perit Dial Int* 8:119–123, 1988
174. Twardowski ZJ, Prowant BF: Can new catheter design eliminate exit site and tunnel infections? *Perspect Periton Dial* 4:5–9, 1986
175. Twardowski ZJ, Dobbie JW, Moore HL, *et al*.: Morphology of peritoneal dialysis catheter tunnel: macroscopy and light microscopy. *Perit Dial Int* 11:237–251, 1991

176. Wright N: The cell proliferation kinetics of the epidermis, in *Biochemistry and Physiology of the Skin*, edited by Goldsmith L, New York, Oxford University Press, 1983, pp 203–229
177. Stricker G, Tenckhoff H: A transcutaneous prosthesis for prolonged access to the peritoneal cavity. *Surgery* 69:70–74, 1971
178. Pru CP, Barriola JA, Garcia V: Pathological evaluation of one cuff peritoneal dialysis catheter tunnel (OCPDCT). *Perit Dial Int* 13:S24 (abstracts), 1993
179. Heppenstall RB, Littooy FN, Fuchs R, *et al*.: Gas tensions in healing tissues of traumatized patients. *Surgery* 75:874–880, 1974
180. Crabtree JH, Fishman A, Siddiqi RA, *et al*.: The risk of infection and peritoneal catheter loss from implant procedure exit site trauma. *Perit Dial Int* 19:366–371, 1999
181. Broughton G, 2nd, Janis JE, Attinger CE: Wound healing: an overview. *Plast Reconstr Surg* 117:1e-S-32e-S, 2006
182. Robson MC: Wound infection. A failure of wound healing caused by an imbalance of bacteria. *Surg Clin North Am* 77:637–650, 1997
183. Bankey P, Fiegel V, Singh R, *et al*.: Hypoxia and endotoxin induce macrophage-mediated suppression of fibroblast proliferation. *J Trauma* 29:972–979; discussion 979–980, 1989
184. Strippoli GF, Tong A, Johnson D, *et al*.: Antimicrobial agents for preventing peritonitis in peritoneal dialysis patients. *Cochrane Database Syst Rev* 18:CD004679, 2004
185. Wilson JR, Mills JG, Prather ID, *et al*.: A toxicity index of skin and wound cleansers used on in vitro fibroblasts and keratinocytes. *Adv Skin Wound Care* 18:373–378, 2005
186. Burks RI: Povidone-iodine solution in wound treatment. *Phys Ther* 78:212–218, 1998
187. Brennan SS, Leaper DJ: The effect of antiseptics on the healing wound: a study using the rabbit ear chamber. *Br J Surg* 72:780–782, 1985
188. Oberg MS, Lindsey D: Do not put hydrogen peroxide or povidone iodine into wounds! *Am J Dis Child* 141:27–28, 1987
189. Laufman H: Current use of skin and wound cleansers and antiseptics. *Am J Surg* 157:359–365, 1989
190. Twardowski ZJ, Prowant BF: Exit-site study methods and results. *Perit Dial Int* 16 Suppl 3:S6-S31, 1996
191. Hepburn H: Delayed primary suture of wounds. *Br Med J* 1:181–183, 1929
192. Elek SD: Experimental staphylococcal infections in the skin of man. *Ann N Y Acad Sci* 65:85–90, 1956
193. Perez-Fontan M, Rodriguez-Carmona A, Rosales M, *et al*.: Incidence and clinical significance of nasal and pericatheter colonization by Gram-negative bacteria among patients undergoing chronic peritoneal dialysis. *Nephrol Dial Transplant* 17:118–122, 2002
194. Eisenberg ES, Ambalu M, Szylagi G, *et al*.: Colonization of skin and development of peritonitis due to coagulase-negative staphylococci in patients undergoing peritoneal dialysis. *J Infect Dis* 156:478–482, 1987
195. Wertheim HF, Melles DC, Vos MC, *et al*.: The role of nasal carriage in Staphylococcus aureus infections. *Lancet Infect Dis* 5:751–762, 2005
196. Boelaert JR, Van Landuyt HW, Gordts BZ, *et al*.: Nasal and cutaneous carriage of Staphylococcus aureus in hemodialysis patients: the effect of nasal mupirocin. *Infect Control Hosp Epidemiol* 17:809–811, 1996
197. Luzar MA, Coles GA, Faller B, *et al*.: Staphylococcus aureus nasal carriage and infection in patients on continuous ambulatory peritoneal dialysis. *N Engl J Med* 322:505–509, 1990
198. Zimakoff J, Bangsgaard Pedersen F, Bergen L, *et al*.: Staphylococcus aureus carriage and infections among patients in four haemo- and peritoneal-dialysis centres in Denmark. The Danish Study Group of Peritonitis in Dialysis (DASPID). *J Hosp Infect* 33:289–300, 1996
199. Nouwen JL, Ott A, Kluytmans-Vandenbergh MF, *et al*.: Predicting the Staphylococcus aureus nasal carrier state: derivation and validation of a "culture rule". *Clin Infect Dis* 39:806–811, 2004
200. Nouwen J, Schouten J, Schneebergen P, *et al*.: Staphylococcus aureus carriage patterns and the risk of infections associated with continuous peritoneal dialysis. *J Clin Microbiol* 44:2233–2236, 2006
201. Vychytil A, Lorenz M, Schneider B, *et al*.: New strategies to prevent Staphylococcus aureus infections in peritoneal dialysis patients. *J Am Soc Nephrol* 9:669–676, 1998
202. Lubrich-Birkner I, Schollmeyer P, Bohler J: Carrier-status for nasal staphylococci does not predict infections in CAPD patients. *Adv Perit Dial* 10:154–157, 1994
203. Twardowski ZJ, Prowant BF: Staphylococcus aureus nasal carriage is not associated with an increased incidence of exit-site infection with the same organism. *Perit Dial Int* 13 Suppl 2:S306–309, 1993
204. Nasal mupirocin prevents Staphylococcus aureus exit-site infection during peritoneal dialysis. Mupirocin Study Group. *J Am Soc Nephrol* 7:2403–2408, 1996
205. Crabtree JH, Hadnott LL, Burchette RJ, *et al*.: Outcome and clinical implications of a surveillance and treatment program for Staphylococcus aureus nasal carriage in peritoneal dialysis patients. *Adv Perit Dial* 16:271–275, 2000
206. Perez-Fontan M, Rosales M, Rodriguez-Carmona A, *et al*.: Treatment of Staphylococcus aureus nasal carriers in CAPD with mupirocin. *Adv Perit Dial* 8:242–245, 1992
207. Bernardini J, Piraino B, Holley J, *et al*.: A randomized trial of Staphylococcus aureus prophylaxis in peritoneal dialysis patients: mupirocin calcium ointment 2% applied to the exit site versus cyclic oral rifampin. *Am J Kidney Dis* 27:695–700, 1996
208. Zimmerman SW, Ahrens E, Johnson CA, *et al*.: Randomized controlled trial of prophylactic rifampin for peritoneal dialysis-related infections. *Am J Kidney Dis* 18:225–231, 1991
209. Furth SL, Donaldson LA, Sullivan EK, *et al*.: Peritoneal dialysis catheter infections and peritonitis in children: a report of the North American Pediatric Renal Transplant Cooperative Study. *Pediatr Nephrol* 15:179–182, 2000
210. Golper TA, Brier ME, Bunke M, *et al*.: Risk factors for peritonitis in long-term peritoneal dialysis: the Network 9 peritonitis and catheter survival studies. Academic Subcommittee of the Steering Committee of the Network 9 Peritonitis and Catheter Survival Studies. *Am J Kidney Dis* 28:428–436, 1996
211. Warady BA, Sullivan EK, Alexander SR: Lessons from the peritoneal dialysis patient database: a report of the North American Pediatric Renal Transplant Cooperative Study. *Kidney Int Suppl* 53:S68–71, 1996
212. Bossert WA, Marks HH: Prevalence and characteristics of periodontal disease in 12,800 persons under periodic dental observation. *J Am Dent Assoc* 52:429–442, 1956
213. Hajek M: *Pathology and treatment of the inflammatory diseases of the nasal accessory sinuses*, 5th ed. St. Louis, Mosby, 1926

214. Raaf JH: Techniques for avoiding surgical complications in chemotherapy-treated cancer patients. *Recent Results Cancer Res* 98:46–52, 1985
215. So SK, Mahan JD, Jr., Mauer SM, *et al.*: Hickman catheter for pediatric hemodialysis: a 3-year experience. *Trans Am Soc Artif Intern Organs* 30:619–623, 1984
216. Crabtree JH, Burchette RJ: Prospective comparison of downward and lateral peritoneal dialysis catheter tunnel-tract and exit-site directions. *Perit Dial Int* 26:677–683, 2006
217. Lye WC, Kour NW, van der Straaten JC, *et al.*: A prospective randomized comparison of the Swan neck, coiled, and straight Tenckhoff catheters in patients on CAPD. *Perit Dial Int* 16 Suppl 1:S333–335, 1996
218. Hwang TL, Huang CC: Comparison of Swan neck catheter with Tenckhoff catheter for CAPD. *Adv Perit Dial* 10:203–205, 1994
219. Eklund BH, Honkanen EO, Kala AR, *et al.*: Peritoneal dialysis access: prospective randomized comparison of the Swan neck and Tenckhoff catheters. *Perit Dial Int* 15:353–356, 1995
220. Eklund BH, Honkanen EO, Kala AR, *et al.*: Catheter configuration and outcome in patients on continuous ambulatory peritoneal dialysis: a prospective comparison of two catheters. *Perit Dial Int* 14:70–74, 1994
221. Moreiras Plaza M, Cuina L, Goyanes GR, *et al.*: Mechanical complications in chronic peritoneal dialysis. *Clin Nephrol* 52:124–130, 1999
222. Smith C: CAPD: one cuff vs two cuff catheters in reference to incidence of infection., in *Frontiers in Peritoneal Dialysis. Proceedings of the III International Symposium on Peritoneal Dialysis 1984*, edited by Maher JF, Winchester JF, Washington, D.C. , New York: Field, Rich, 1986, pp 181–182
223. Piraino B, Bailie GR, Bernardini J, *et al.*: Peritoneal dialysis-related infections recommendations: 2005 update. *Perit Dial Int* 25:107–131, 2005
224. Ash SR: Chronic peritoneal dialysis catheters: overview of design, placement, and removal procedures. *Semin Dial* 16:323–334, 2003
225. Diaz-Buxo J, Geissinger W: Single cuff versus double cuff Tenckhoff catheter. *Perit Dial Bull* 4 (suppl. 3):S100–102, 1984
226. Honda M, Iitaka K, Kawaguchi H, *et al.*: The Japanese National Registry data on pediatric CAPD patients: a ten-year experience. A report of the Study Group of Pediatric PD Conference. *Perit Dial Int* 16:269–275, 1996
227. Favazza A, Petri R, Montanaro D, *et al.*: Insertion of a straight peritoneal catheter in an arcuate subcutaneous tunnel by a tunneler: long-term experience. *Perit Dial Int* 15:357–362, 1995
228. Lindblad AS, Novak JW, Nolph KD, *et al.*: The 1987 USA National CAPD Registry report. *ASAIO Trans* 34:150–156, 1988
229. Catheter-related factors and peritonitis risk in CAPD patients. *Am J Kidney Dis* 20:48–54, 1992
230. Eklund B, Honkanen E, Kyllonen L, *et al.*: Peritoneal dialysis access: prospective randomized comparison of single-cuff and double-cuff straight Tenckhoff catheters. *Nephrol Dial Transplant* 12:2664–2666, 1997
231. Ross EA, Batich CD, Clapp WL, *et al.*: Tissue adhesion to bioactive glass-coated silicone tubing in a rat model of peritoneal dialysis catheters and catheter tunnels. *Kidney Int* 63:702–708, 2003
232. Schroeder H, Page R: The normal periodontium, in *Periodontal Disease*, edited by Schluger S, Youdelis R, Page R, Philadelphia, Lea & Febiger, 1978, pp 7–55
233. Rottembourg J, Quinton W, JPDurande, *et al.*: Wings as subcutaneous cuff in prevention of exit-site infection in CAPD patients. *Perit Dial Bull* 7 (suppl.):S63, 1987
234. Jansen JA, Walboomers XF: A new titanium fiber mesh-cuffed peritoneal dialysis catheter: an experimental animal study. *J Mater Sci Mater Med* 12:1033–1037, 2001
235. Mehall JR, Saltzman DA, Jackson RJ, *et al.*: Catheter materials affect the incidence of late blood-borne catheter infection. *Surg Infect (Larchmt)* 2:225–229; discussion 229–230, 2001
236. Crabtree JH, Siddiqi RA, Chung JJ, *et al.*: Long-term experience with polyurethane, pail handle, coiled tip peritoneal dialysis catheters. *Asaio J* 44:309–313, 1998
237. Montenegro J, Saracho R, Aguirre R, *et al.*: Exit-site care with ciprofloxacin otologic solution prevents polyurethane catheter infection in peritoneal dialysis patients. *Perit Dial Int* 20:209–214, 2000
238. Crabtree JH: Fragmentation of polyurethane peritoneal dialysis catheter during explantation. *Perit Dial Int* 24:601–602, 2004
239. Twardowski ZJ, Prowant BF: Appearance and classification of healing peritoneal catheter exit sites. *Perit Dial Int* 16 Suppl 3:S71-S93, 1996
240. Twardowski ZJ, Prowant BF: Classification of normal and diseased exit sites. *Perit Dial Int* 16 Suppl 3:S32-S50, 1996
241. Twardowski ZJ, Prowant BF: Current approach to exit-site infections in patients on peritoneal dialysis. *Nephrol Dial Transplant* 12:1284–1295, 1997
242. Gupta B, Bernardini J, Piraino B: Peritonitis associated with exit site and tunnel infections. *Am J Kidney Dis* 28:415–419, 1996
243. Bunke M, Brier ME, Golper TA: Pseudomonas peritonitis in peritoneal dialysis patients: the Network #9 Peritonitis Study. *Am J Kidney Dis* 25:769–774, 1995
244. Piraino B, Bernardini J, Sorkin M: The influence of peritoneal catheter exit-site infections on peritonitis, tunnel infections, and catheter loss in patients on continuous ambulatory peritoneal dialysis. *Am J Kidney Dis* 8:436–440, 1986
245. Mujais S: Microbiology and outcomes of peritonitis in North America. *Kidney Int Suppl* 70:S55–62, 2006
246. Schaefer F, Klaus G, Muller-Wiefel DE, *et al.*: Intermittent versus continuous intraperitoneal glycopeptide/ceftazidime treatment in children with peritoneal dialysis-associated peritonitis. The Mid-European Pediatric Peritoneal Dialysis Study Group (MEPPS). *J Am Soc Nephrol* 10:136–145, 1999
247. Holley JL, Moss A: Improved diagnosis of CAPD exit-site infections with catheter manipulation and the use of a grading system. *Adv Perit Dial* 4:177–180, 1988
248. Schroder CH: Validation of a scoring system for exit-site evaluation. *Perit Dial Int* 21:623–624, 2001
249. Prowant BF, Warady BA, Nolph KD: Peritoneal dialysis catheter exit-site care: results of an international survey. *Perit Dial Int* 13:149–154, 1993
250. Prowant BF, Twardowski ZJ: Recommendations for exit care. *Perit Dial Int* 16 Suppl 3:S94-S99, 1996
251. Turner K, Edgar D, Hair M, *et al.*: Does catheter immobilization reduce exit-site infections in CAPD patients? *Adv Perit Dial* 8:265–268, 1992

252. Prowant BF, Schmidt LM, Twardowski ZJ, *et al.*: Peritoneal dialysis catheter exit site care. *Anna J* 15:219–223, 1988
253. Luzar MA, Brown CB, Balf D, *et al.*: Exit-site care and exit-site infection in continuous ambulatory peritoneal dialysis (CAPD): results of a randomized multicenter trial. *Perit Dial Int* 10:25–29, 1990
254. Wadhwa Nk Fau–Reddy GH, Reddy GH: Exit-site care in peritoneal dialysis. *Contrib Nephrol* 154:117–124, 2007
255. Grosman MD, Mosquera VM, Hernandez MG, *et al.*: 3% Amuchina is as effective as the 50% concentration in the prevention of exit-site infection in children on chronic peritoneal dialysis. *Adv Perit Dial* 21:148–150, 2005
256. Yanagisawa T, Lee JT, Wu HC, *et al.*: Relationship of protein structure of isoleucyl-tRNA synthetase with pseudomonic acid resistance of Escherichia coli. A proposed mode of action of pseudomonic acid as an inhibitor of isoleucyl-tRNA synthetase. *J Biol Chem* 269:24304–24309, 1994
257. Thodis E, Passadakis P, Panagoutsos S, *et al.*: The effectiveness of mupirocin preventing Staphylococcus aureus in catheter-related infections in peritoneal dialysis. *Adv Perit Dial* 16:257–261, 2000
258. Mahajan S, Tiwari SC, Kalra V, *et al.*: Effect of local mupirocin application on exit-site infection and peritonitis in an Indian peritoneal dialysis population. *Perit Dial Int* 25:473–477, 2005
259. Casey M, Taylor J, Clinard P, *et al.*: Application of mupirocin cream at the catheter exit site reduces exit-site infections and peritonitis in peritoneal dialysis patients. *Perit Dial Int* 20:566–568, 2000
260. Uttley L, Vardhan A, Mahajan S, *et al.*: Decrease in infections with the introduction of mupirocin cream at the peritoneal dialysis catheter exit site. *J Nephrol* 17:242–245, 2004
261. Zeybel M, Ozder A, Sanlidag C, *et al.*: The effects of weekly mupirocin application on infections in continuous ambulatory peritoneal dialysis patients. *Adv Perit Dial* 19:198–201, 2003
262. Al-Hilali NA, Ninan VT, Al-Humoud HA, *et al.*: Mupirocin once weekly reduces the incidence of catheter exit-site infection in peritoneal dialysis patients. *Perit Dial Int* 25:91–92, 2005
263. Bernardini J, Bender F, Florio T, *et al.*: Randomized, double-blind trial of antibiotic exit site cream for prevention of exit site infection in peritoneal dialysis patients. *J Am Soc Nephrol* 16:539–545, 2005
264. Strippoli GF, Tong A, Johnson D, *et al.*: Antimicrobial agents to prevent peritonitis in peritoneal dialysis: a systematic review of randomized controlled trials. *Am J Kidney Dis* 44:591–603, 2004
265. Amato D, de Jesus Ventura M, Miranda G, *et al.*: Staphylococcal peritonitis in continuous ambulatory peritoneal dialysis: colonization with identical strains at exit site, nose, and hands. *Am J Kidney Dis* 37:43–48, 2001
266. Falagas ME, Fragoulis KN, Bliziotis IA: Oral rifampin for prevention of S. aureus carriage-related infections in patients with renal failure–a meta-analysis of randomized controlled trials. *Nephrol Dial Transplant* 21:2536–2542, 2006
267. Tacconelli E, Carmeli Y, Aizer A, *et al.*: Mupirocin prophylaxis to prevent Staphylococcus aureus infection in patients undergoing dialysis: a meta-analysis. *Clin Infect Dis* 37:1629–1638, 2003
268. Rao SP, Oreopoulos DG: Unusual complications of a polyurethane PD catheter. *Perit Dial Int* 17:410–412, 1997
269. Perez-Fontan M, Rosales M, Rodriguez-Carmona A, *et al.*: Mupirocin resistance after long-term use for Staphylococcus aureus colonization in patients undergoing chronic peritoneal dialysis. *Am J Kidney Dis* 39:337–341, 2002
270. Annigeri R, Conly J, Vas S, *et al.*: Emergence of mupirocin-resistant Staphylococcus aureus in chronic peritoneal dialysis patients using mupirocin prophylaxis to prevent exit-site infection. *Perit Dial Int* 21:554–559, 2001
271. Conly JM, Vas S: Increasing mupirocin resistance of Staphylococcus aureus in CAPD–should it continue to be used as prophylaxis? *Perit Dial Int* 22:649–652, 2002
272. Lobbedez T, Gardam M, Dedier H, *et al.*: Routine use of mupirocin at the peritoneal catheter exit site and mupirocin resistance: still low after 7 years. *Nephrol Dial Transplant* 19:3140–3143, 2004
273. Twardowski ZJ, Ryan LP, Kennedy JM: Catheter break-in for continuous ambulatory peritoneal dialysis–University of Missouri experience. *Perit Dial Bull* 4 (suppl. 3):S110–111, 1984
274. Ash SR, Carr DJ, Diaz-Buxo JA: Peritoneal access devices: hydraulic function and compatibility, in *Clinical Dialysis*, edited by Nissenson AR, Fine RN, Gentile DE, 2nd ed, Nor-walk, Appleton & Lange, 1990, pp 212–239
275. Krishnan RG, Moghal NE: Tissue plasminogen activator for blocked peritoneal dialysis catheters. *Pediatr Nephrol* 21:300, 2006
276. Shea M, Hmiel SP, Beck AM: Use of tissue plasminogen activator for thrombolysis in occluded peritoneal dialysis catheters in children. *Adv Perit Dial* 17:249–252, 2001
277. Benevent D, Peyronnet P, Brignon P, *et al.*: Urokinase infusion for obstructed catheters and peritonitis. *Perit Dial Bull* 5:77, 1985
278. Hashimoto Y, Yano S, Nakanishi Y, *et al.*: A simple method for opening an obstructed peritoneal catheter using an infusion accelerator. *Adv Perit Dial* 12:227–230, 1996
279. Twardowski ZJ, Pasley K: Reversed one-way obstruction of the peritoneal catheter (the accordion clot). *Perit Dial Int* 14:296–297, 1994
280. O'Regan S, Garel L, Patriquin H, *et al.*: Outflow Obstruction: Whiplash Technique for Catheter Mobilization. *Perit Dial Int* 8:265–268, 1988
281. Honkanen E, Eklund B, Laasonen L, *et al.*: Reposition of a displaced peritoneal catheter: the Helsinki whiplash method. *Adv Perit Dial* 6:159–164, 1990
282. Diaz-Buxo JA, Turner MW, Nelms M: Fluoroscopic manipulation of Tenckhoff catheters: outcome analysis. *Clin Nephrol* 47:384–388, 1997
283. Yoshihara K, Yoshi S, Miyagi S: Alpha replacement method for the displaced Swan neck catheter. *Adv Perit Dial* 9:227–230, 1993
284. Schleifer CR, Ziemek H, Teehan BP, *et al.*: Migration of peritoneal catheters: personal experience and a survey of 72 other units. *Perit Dial Bull* 7:189–193, 1987
285. Twardowski ZJ: Malposition and poor drainage of peritoneal catheters. *Seminars in Dialysis (Dialysis Clinic section)* 3:57, 1990
286. Twardowski ZJ: Catheter exit site care in the long-term. *Contrib Nephrol* 142:422–434, 2004
287. Strauss FG, Holmes DL, Nortman DF, *et al.*: Hypertonic saline compresses: therapy for complicated exit-site infections. *Adv Perit Dial* 9:248–250, 1993
288. Twardowski Z: Peritoneal catheter exit site infections: Prevention, diagnosis, treatment, and future directions. *Semin Dial* 5:305–315, 1992

289. Kazmi HR, Raffone FD, Kliger AS, *et al.*: Pseudomonas exit site infections in continuous ambulatory peritoneal dialysis patients. *J Am Soc Nephrol* 2:1498–1501, 1992
290. Bertone AL: Management of exuberant granulation tissue. *Vet Clin North Am Equine Pract* 5:551–562, 1989
291. Khanna R, Twardowski ZJ: Recommendations for treatment of exit-site pathology. *Perit Dial Int* 16 Suppl 3:S100-S104, 1996
292. Vychytil A, Lilaj T, Lorenz M, *et al.*: Ultrasonography of the catheter tunnel in peritoneal dialysis patients: what are the indications? *Am J Kidney Dis* 33:722–727, 1999
293. Keane WF, Bailie GR, Boeschoten E, *et al.*: Adult peritoneal dialysis-related peritonitis treatment recommendations: 2000 update. *Perit Dial Int* 20:396–411, 2000
294. Plum J, Sudkamp S, Grabensee B: Results of ultrasound-assisted diagnosis of tunnel infections in continuous ambulatory peritoneal dialysis. *Am J Kidney Dis* 23:99–104, 1994
295. Kwan Th Fau–Tong MK-H, Tong Mk Fau–Siu Y-P, Siu Yp Fau–Leung K-T, *et al.*: Ultrasonography in the management of exit site infections in peritoneal. *Nephrology (Carlton)* 9:348–352, 2004
296. Majkowski NL, Mendley SR: Simultaneous removal and replacement of infected peritoneal dialysis catheters. *Am J Kidney Dis* 29:706–711, 1997
297. Posthuma N, Borgstein PJ, Eijsbouts Q, *et al.*: Simultaneous peritoneal dialysis catheter insertion and removal in catheter-related infections without interruption of peritoneal dialysis. *Nephrol Dial Transplant* 13:700–703, 1998
298. Crabtree JH, Burchette RJ: Surgical salvage of peritoneal dialysis catheters from chronic exit-site and tunnel infections. *Am J Surg* 190:4–8, 2005
299. Scalamogna A, De Vecchi A, Maccario M, *et al.*: Cuff-shaving procedure. A rescue treatment for exit-site infection unresponsive to medical therapy. *Nephrol Dial Transplant* 10:2325–2327, 1995
300. Suh H, Wadhwa NK, Cabralda T, *et al.*: Persistent exit-site/tunnel infection and subcutaneous cuff removal in PD patients. *Adv Perit Dial* 13:233–236, 1997
301. Nichols WK, Nolph KD: A technique for managing exit site and cuff infections in Tenckhoff catheters. *Perit Dial Bull* 3:S3-S5, 1983
302. Clouatre Y, Cartier P, Charbonneau R, *et al.*: Outpatient CAPD catheter salvage for persistent exit-site/tunnel infection. *Nephrol Dial Transplant* 15:231–234, 2000
303. Wu YM, Tsai MK, Chao SH, *et al.*: Surgical management of refractory exit-site/tunnel infection of Tenckhoff catheter: technical innovations of partial replantation. *Perit Dial Int* 19:451–454, 1999
304. Cheung AH, Wheeler MS, Limm WM, *et al.*: A salvage technique for continuous ambulatory peritoneal dialysis catheters with exit-site infections. *Am J Surg* 170:60–61, 1995
305. Twardowski ZJ, Prowant BF, Nichols WK, *et al.*: Six-year experience with Swan neck presternal peritoneal dialysis catheter. *Perit Dial Int* 18:598–602, 1998
306. Holley JL, Bernardini J, Piraino B: Infecting organisms in continuous ambulatory peritoneal dialysis patients on the Y-set. *Am J Kidney Dis* 23:569–573, 1994
307. Gokal R: Peritoneal dialysis. Prevention and control of infection. *Drugs Aging* 17:269–282, 2000
308. Read RR, Eberwein P, Dasgupta MK, *et al.*: Peritonitis in peritoneal dialysis: bacterial colonization by biofilm spread along the catheter surface. *Kidney Int* 35:614–621, 1989
309. Peritonitis in continuous ambulatory peritoneal dialysis (CAPD): a multi-centre randomized clinical trial comparing the Y connector disinfectant system to standard systems. Canadian CAPD Clinical Trials Group. *Perit Dial Int* 9:159–163, 1989
310. Grefberg N, Danielson BG, Nilsson P, *et al.*: An unusual complication of the Toronto Western Hospital catheter *Perit Dial Bull*:219, 1983
311. Dasgupta MK: Biofilms and infection in dialysis patients. *Semin Dial* 15:338–346, 2002
312. Finkelstein ES, Jekel J, Troidle L, *et al.*: Patterns of infection in patients maintained on long-term peritoneal dialysis therapy with multiple episodes of peritonitis. *Am J Kidney Dis* 39:1278–1286, 2002
313. Stewart PS, Costerton JW: Antibiotic resistance of bacteria in biofilms. *Lancet* 358:135–138, 2001
314. Whaley-Connell A, Khanna R: Relapsing peritonitis in continuous ambulatory peritoneal dialysis and an unconventional approach to treatment. *Adv Perit Dial* 20:71–73, 2004
315. Mactier RA, Sprosen TS, Gokal R, *et al.*: Bicarbonate and bicarbonate/lactate peritoneal dialysis solutions for the treatment of infusion pain. *Kidney Int* 53:1061–1067, 1998
316. Diaz-Buxo JA: Complications of peritoneal dialysis catheters: early and late. *Int J Artif Organs* 29:50–58, 2006
317. Diaz-Buxo JA: Peritoneal dialysis catheter malfunction due to compartmentalization. *Perit Dial Int* 17:209–210, 1997
318. Abouljoud MS, Cruz C, Dow RW, *et al.*: Peritoneal dialysis catheter obstruction by a fallopian tube: a case report. *Perit Dial Int* 12:257–258, 1992
319. Schleifer CR, Zeimek H, Teehan BP: Migration of peritoneal catheters: personal experience and survey of 72 other units. *Perit Dial Bull* 7:189–193, 1987
320. Helfrich BG, Pechan BW, Alijani MR, *et al.*: Reduction of catheter complications with lateral placement. *Perit Dial Bull* 3:S2-S4, 1983
321. Twardowski ZJ: Clinical value of standardized equilibration tests in CAPD patients. *Blood Purif* 7:95–108, 1989
322. Tse KC, Yip PS, Lam MF, *et al.*: Recurrent hemoperitoneum complicating continuous ambulatory peritoneal dialysis. *Perit Dial Int* 22:488–491, 2002
323. Miller R, Denman R, Saltissi D, *et al.*: Erosion of a mesenteric vessel by a Tenckhoff catheter. *Perit Dial Int* 16:528–529, 1996
324. Van der Niepen P, Sennesael JJ, Verbeelen DL: Massive hemoperitoneum due to spleen injury by a dislocated Tenckhoff catheter. *Perit Dial Int* 14:90–91, 1994
325. de los Santos CA, d'Avila DO, von Eye O, *et al.*: Rupture of the spleen: a complication of continuous ambulatory peritoneal dialysis. *Perit Dial Bull* 6:203–204, 1986
326. Schroder CH, Rieu P, de Jong MC: Peritoneal laceration: a rare cause of scrotal edema in a 2-year-old boy. *Adv Perit Dial* 9:329–330, 1993
327. della Volpe M, Iberti M, Ortensia A, *et al.*: Erosion of the sigmoid by a permanent peritoneal catheter (letter). *Perit Dial Bull* 4:108, 1984

328. Valles M, Cantarell C, Vila J, *et al.*: Delayed perforation of the colon by a Tenckhoff catheter. *Perit Dial Bull* 2:190, 1982
329. Kourie TB, Botha JR: Erosion of the caecum by a Tenkhoff catheter. A case report. *S Afr J Surg* 23:117–118, 1985
330. Jamison MH, Fleming SJ, Ackrill P, *et al.*: Erosion of rectum by Tenckhoff catheter. *Br J Surg* 75:360, 1988
331. Watson LC, Thompson JC: Erosion of the colon by a long-dwelling peritoneal dialysis catheter. *Jama* 243:2156–2157, 1980
332. Askenazi D, Katz A, Tenney F, *et al.*: An unusual case of peritoneal dialysis malfunction. *Kidney Int* 72:524, 2007
333. Bradley AJ, Mamtora H, Pritchard N: Transvaginal leak of peritoneal dialysate demonstrated by CT peritoneography. *Br J Radiol* 70:652–653, 1997
334. Diaz-Buxo JA, Burgess P, Walker PJ: Peritoneo-vaginal fistula-Unusual complication of peritoneal dialysis. *Perit Dial Int* 3:142–143, 1983
335. Usha K, Ponferrada L, Prowant BF, *et al.*: Repair of chronic peritoneal dialysis catheter. *Perit Dial Int* 18:419–423, 1998
336. Crabtree JH: Clinical biodurability of aliphatic polyether based polyurethanes as peritoneal dialysis catheters. *Asaio J* 49:290–294, 2003
337. Riu S, Ruiz CG, Martinez-Vea A, *et al.*: Spontaneous rupture of polyurethane peritoneal catheter. A possible deleterious effect of mupirocin ointment. *Nephrol Dial Transplant* 13:1870–1871, 1998
338. Ward RA, Klein E, Wathen RL: Peritoneal catheters. In: Investigation of the risks and hazards with devices associated with peritoneal dialysis and sorbent regenerated dialy-sate delivery systems. *Perit Dial Bull* 3 (suppl. 3):S9–17, 1983
339. Lamba NMK, Woodhouse K, Cooper SL: *Polyurethanes in Biomedical Applications*. Boca Raton, FL, CRC Press, 1998
340. Mathur AB, Collier TO, Kao WJ, *et al.*: In vivo biocompatibility and biostability of modified polyurethanes. *J Biomed Mater Res* 36:246–257, 1997
341. Vondracek P, Dolezel B: Biostability of medical elastomers: a review. *Biomaterials* 5:209–214, 1984
342. Coury AJ, Stokes KB, Cahalan PT, *et al.*: Biostability considerations for implantable polyurethanes. *Life Support Syst* 5:25–39, 1987
343. Gokal R, Ramos JM, Ward MK, *et al.*: "Eosinophilic" peritonitis in continuous ambulatory peritoneal dialysis (CAPD). *Clin Nephrol* 15:328–330, 1981
344. Solary E, Cabanne JF, Tanter Y, *et al.*: Evidence for a role of plasticizers in 'eosinophilic' peritonitis in continuous ambulatory peritoneal dialysis. *Nephron* 42:341–342, 1986
345. Daugirdas JT, Leehey DJ, Popli S, *et al.*: Induction of peritoneal fluid eosinophilia and/or monocytosis by intraperitoneal air injection. *Am J Nephrol* 7:116–120, 1987
346. Fontan MP, Rodriguez-Carmona A, Galed I, *et al.*: Incidence and significance of peritoneal eosinophilia during peritoneal dialysis-related peritonitis. *Perit Dial Int* 23:460–464, 2003
347. Parikova A, Zweers MM, Struijk DG, *et al.*: Peritoneal effluent markers of inflammation in patients treated with icodextrin-based and glucose-based dialysis solutions. *Adv Perit Dial* 19:186–190, 2003
348. MacGinley R, Cooney K, Alexander G, *et al.*: Relapsing culture-negative peritonitis in peritoneal dialysis patients exposed to icodextrin solution. *Am J Kidney Dis* 40:1030–1035, 2002
349. Chan MK, Chow L, Lam SS, *et al.*: Peritoneal eosinophilia in patients on continuous ambulatory peritoneal dialysis: a prospective study. *Am J Kidney Dis* 11:180–183, 1988
350. Nassberger L, Arbin A: Eosinophilic peritonitis–hypothesis. *Nephron* 46:103–104, 1987
351. Leung AC, Orange G, Henderson IS: Intraperitoneal hydrocortisone in eosinophilic peritonitis associated with continuous ambulatory peritoneal dialysis. *Br Med J (Clin Res Ed)* 286:766, 1983
352. Thakur SS, Unikowsky B, Prichard S: Eosinophilic peritonitis in CAPD: treatment with prednisone and diphenhydramine. *Perit Dial Int* 17:402–403, 1997
353. Asghar R, Woodrow G, Turney JH: A case of eosinophilic peritonitis treated with oral corticosteroids. *Perit Dial Int* 20:579–580, 2000
354. Tang S, Lo CY, Lo WK, *et al.*: Resolution of eosinophilic peritonitis with ketotifen. *Am J Kidney Dis* 30:433–436, 1997
355. Kurihara S, Tani Y, Tateishi K, *et al.*: Allergic eosinophilic dermatitis due to silicone rubber: A rare but troublesome complication of the Tenckhoff catheter. *Perit Dial Int* 5:65–67, 1985
356. Scanziani R, Dozio B, Caimi F, *et al.*: Peritoneography and peritoneal computerized tomography: a new approach to non-infectious complications of CAPD. *Nephrol Dial Transplant* 7:1035–1038, 1992
357. Hawkins SP, Homer JA, Murray BB, *et al.*: Modified computed tomography peritoneography: clinical utility in continuous ambulatory peritoneal dialysis patients. *Australas Radiol* 44:398–403, 2000
358. Karahan OI, Taskapan H, Tokgoz B, *et al.*: Continuous ambulatory peritoneal dialysis. *Acta Radiol* 43:170–174, 2002
359. Prokesch RW, Schima W, Schober E, *et al.*: Complications of continuous ambulatory peritoneal dialysis: findings on MR peritoneography. *AJR Am J Roentgenol* 174:987–991, 2000
360. Prischl FC, Muhr T, Seiringer EM, *et al.*: Magnetic resonance imaging of the peritoneal cavity among peritoneal dialysis patients, using the dialysate as "contrast medium". *J Am Soc Nephrol* 13:197–203, 2002
361. Yavuz K, Erden A, Ates K, *et al.*: MR peritoneography in complications of continuous ambulatory peritoneal dialysis. *Abdom Imaging* 30:361–368, 2005
362. Perazella MA, Rodby RA: Gadolinium use in patients with kidney disease: a cause for concern. *Semin Dial* 20:179–185, 2007
363. Berman C, Velchik MG, Shusterman N, *et al.*: The clinical utility of the Tc-99m SC intraperitoneal scan in CAPD patients. *Clin Nucl Med* 14:405–409, 1989
364. Juergensen PH, Rizvi H, Caride VJ, *et al.*: Value of scintigraphy in chronic peritoneal dialysis patients. *Kidney Int* 55:1111–1119, 1999
365. Johnson BF, Segasby CA, Holroyd AM, *et al.*: A method for demonstrating subclinical inguinal herniae in patients undergoing peritoneal dialysis: the isotope 'peritoneoscrotogram'. *Nephrol Dial Transplant* 2:254–257, 1987
366. Scanziani R, Pozzi M, Pisano L, *et al.*: Imaging work-up for peritoneal access care and peritoneal dialysis complications. *Int J Artif Organs* 29:142–152, 2006
367. Vychytil A, Lorenz M, Schneider B, *et al.*: New criteria for management of catheter infections in peritoneal dialysis patients using ultrasonography. *J Am Soc Nephrol* 9:290–296, 1998
368. Taylor PM: Image-guided peritoneal access and management of complications in peritoneal dialysis. *Semin Dial* 15:250–258, 2002