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History and Development of the Access for Peritoneal Dialysis

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Introduction

One of the most important components of the peritoneal dialysis system is a permanent and trouble-free access to the peritoneal cavity. Although in the development of peritoneal access various ideas have been tried, nowadays only catheters penetrating the abdominal integument are in use. Unfortunately, none of the currently used catheters is trouble free; poor dialysate drainage, pericatheter leaks, exit site and tunnel infections, and recurrent peritonitis episodes are frequently encountered. Therefore, there is an incessant search for new technological solutions, including new shapes of intraperitoneal and intramural catheter segments and new catheter materials are tried. This chapter will present a brief history of peritoneal catheter development and describe the designs of the most commonly used catheters.

Early History of Catheter Development (1923–1968)

In the early years of peritoneal dialysis the access was not specifically designed for the peritoneal dialysis, rather the available equipment used for other purposes was adapted. Ganter [1] used a metal trocar; Rosenak and Siwon [2] adjusted a glass cannula with multiple side holes used for surgical drains. Engel and Kerkes [3] from Prague used a glass catheter with a mushroom-like opening inside the peritoneum to maximize fluid distribution and prevent obstruction. Reid et al. [4] used a Foley catheter. Major problems in these years were leakage, infection and catheter occlusion by clot or omental fat sucked into the catheter lumen. Fine et al. [5] created a subcutaneous tunnel to hamper periluminal bacterial migration into the peritoneal cavity. They adapted a stainless steel sump drain for dialysate outflow and a rubber mushroom catheter for dialysis solution inflow. Although these innovations showed some improvement in infection rate and drainage, the overall results were not satisfactory and pericatheter leaks were frequent. Some unusual problems that we do not see these days were rigidity of the tube with resulting pressure to viscera, suction of contaminated air into the peritoneal cavity, and difficulties of proper aseptic fixation of the tube to the abdominal wall.

Stephen Rosenak, a Hungarian physician, who became interested in continuous flow peritoneal dialysis in his medical student years in the 1920s [2] while working with Oppenheimer at the Mt. Sinai Hospital in New York, for the first time developed an access specifically for peritoneal dialysis [6]. The Rosenak and Oppenheimer access consisted of a stainless steel flexible coil attached to a rubber drain. The outer portion of the steel tube was attached to an adjustable tie plate for fixation and prevention of leakage. The access was suitable for continuous flow dialysis with inflow through the outer tube and outflow through the inner tube. This device did not gain popularity because major problems were not solved: the rigid tube irritated viscera; dialysate leakage and peritoneal contamination were not eliminated.

A major advance was the introduction of less rigid materials by French physicians. Derot et al. [7] and Marcel Legrain, while working with John Merril [8] in New York used polyvinyl tube for peritoneal dialysis in acute renal failure. The next major progress was made in late 1950s when Maxwell et al. [9] from the University of California in Los Angeles introduced a polyamide (nylon) catheter with multiple tiny distal perforations. The small diameter of perforations prevented particles of omentum from entering the catheter. At the same time, Doolan et al. [10] 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 1960s, Dr. Belding Scribner from Seattle invited Dr. Boen from the Netherlands to continue his peritoneal dialysis research. With limited capacity for hemodialysis, Scribner expected that peritoneal dialysis would be a good alternative for treating a larger number of patients. Boen implanted a Teflon® button in the abdominal wall. Through this button a long catheter was inserted into the peritoneal cavity. After each dialysis the catheter was removed and the button was capped; thus, periodic peritoneal dialysis for chronic renal failure was introduced [11]. Because the method was plagued by frequent peritonitis episodes, Boen et al. [12] in 1963 developed the repeated puncture method. The available catheters, which were semirigid and poorly secured with a short pericatheter path, were not suitable for permanent implantation. For each dialysis, a new catheter had to be inserted. The insertion procedure required penetration of the abdominal wall with a paracentesis trocar. The resulting abdominal opening was of greater diameter than the catheter and pericatheter leaks were frequent.

To circumvent the dialysate leakage problem, Weston and Roberts [13] invented a stylet catheter, which was inserted without a trocar. A sharp stainless steel stylet inserted through the catheter was used to penetrate the abdominal wall. As a result, the abdominal opening fitted snugly around the catheter, thereby preventing leakage. This type of catheter is still being used for acute renal failure.

In another approach to facilitate repeated puncture, Mallette et al. [14] implanted a subcutaneous button. Only skin and subcutaneous tissue had to be penetrated for each catheter insertion. Jacob and Deane [15] used a Teflon® rod to replace the catheter between dialyses. No puncture was necessary. To decrease the possibility of leakage around the catheter, Barry et al. [16] revived the Rosenak and Oppenheimer idea for providing an external seal. They used a Plexiglas disc and a polyvinyl balloon instead of a metal plate for the trans-abdominal cannula. A polyvinyl catheter was inserted through the cannula for each dialysis. The necessity of repeated puncture or catheter insertion through the permanent opening has not gained popularity because this was impractical, especially for the home peritoneal dialysis. These catheters were also plagued with infections, dialysate leaks, and obstructions.

A major step forward in creating a permanent peritoneal access was made in 1964. Gutch [17] noticed lower protein losses with silicone rubber catheters as compared to polyvinyl ones, which suggested less irritation of the peritoneum with a new material. About the same time, Russell Palmer, a physician at the Canadian Army Medical Corps, was developing a peritoneal access made of polyethylene, polypropylene, and nylon [18]. These catheters were relatively rigid and not better than the others available at that time. He was looking for a better material, softer, and more biocompatible. With the help of Wayne Quinton, already successful in manufacturing silicone rubber shunts for hemodialysis, they developed a catheter, which is a prototype of currently used coiled catheters [19]. The catheter was made of silicone 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. To impede further infection and leakage, a triflanged 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 [20]. After an initial few dialyses in the hospital, the patients would be trained for home dialysis. On the weekends, Tenckhoff would go to the patient's home, insert a temporary 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. He was thinking of a more practical solution.

In 1968, McDonald et al. [21] developed an external seal composed of a polyester (Dacron®) sleeve and a 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.

In the same year, Tenckhoff and Schechter [22] published the results of their studies on a new catheter. Their catheter was an improved version of the Palmer catheter. An intra-abdominal flange was replaced by a Dacron® cuff, a subcutaneous tunnel was shortened and a 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. The 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 a straight intraperitoneal segment facilitated catheter implantation at the bedside with the aid of a specially designed trocar. To avoid excessive bleeding the catheter was inserted through the midline. The Tenckhoff catheter has become the gold standard of peritoneal access. 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. Few complications were reported in patients treated by periodic peritoneal dialysis in the supine position. However, in patients treated with continuous ambulatory peritoneal dialysis, complications became more frequent, due to high intra-abdominal pressure in the upright position and numerous daily manipulations. Nevertheless, even today, 35 years later, the Tenckhoff catheter in its original form is one of the most widely used catheter types.

Modifications to Mitigate Complications of the Tenckhoff Catheter

The most common complications of the Tenckhoff catheter included exit/tunnel infection, external cuff extrusion, obstruction (which was usually a sequela 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.

Exit Infection

To prevent exit infection, a subcutaneous catheter was developed by Stephen et al. [23]. The catheter had two tubes in the peritoneal cavity, and a subcutaneous container. The container was to be punctured for each dialysis. Another subcutaneous catheter was developed by Gotloib et al. [24]. Yet another approach to decrease exit site infection rates was to position the subcutaneous cuff at the skin level [25]. Unfortunately, contrary to expectations, such a position tends to increase infection rates [26].

Catheter Obstruction

To decrease catheter migration and omental wrapping the intraperitoneal segment of the catheter was provided with a saline inflatable balloon [27] or discs [28]. Valli et al. [29, 30] revived an idea of Goldberg and Hill [27] and made a silicone rubber catheter with a balloon-shaped intraperitoneal segment surrounding the catheter tip. Ash et al. [31] replaced the intraperitoneal tubing with a disc located immediately beneath the abdominal wall. Recently Ash et al. [32, 33] 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 lies against the parietal peritoneum and is connected perpendicularly to a transabdominal tube, thus creating a 'T'-shaped catheter. Both catheters cannot migrate, but still may be obstructed by bowels, adhesions, or omentum.

Another approach was undertaken by Chiaramonte et al. [34–36] from Vicenza. Because the best position of the catheter tip is the true pelvis, the Vicenza group decided to shorten the catheter and implant it very low, just a few centimeters above the symphysis pubis. Such a catheter has 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. According to the authors, the long-term experience with Vicenza catheter was very positive [36]: the catheter obstruction rate was very low, and 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, near the pubis, insertion site of the catheter, where intra-abdominal pressure in the upright position is higher compared to that of the insertion site of Tenckhoff catheter near the navel.

As mentioned above, the omentum rarely reaches below the pelvic brim, so keeping the catheter tip in the true pelvis should prevent catheter migration with subsequent obstruction. To keep the catheter tip in the true pelvis, Di Paolo et al. [37] decided to incorporate a tungsten weight at the catheter tip. In the upright position, such a catheter tip tends to remain in the true pelvis due to gravity. In the original study, 32 'self-locating' catheters were followed for 468 patient-months and compared to 26 Tenckhoff catheters followed for 415 patient-months. No translocations of the self-locating catheter were observed, whereas nine dislocations occurred with Tenckhoff catheters. The rate of Tenckhoff catheter dislocations was unusually high in this study. The other complications were similar with both types of catheters. The lower dislocation rates of the self-locating catheter compared to Tenckhoff catheter were confirmed by other groups [38, 39]. No bowel or bladder perforations were observed with self-locating catheters [39].

Pericatheter Leak

As pericatheter leakage was frequently observed in ambulatory peritoneal dialysis patients, a design to prevent this complication was introduced in Toronto in 1979 [40], shortly after continuous ambulatory peritoneal dialysis was introduced into the treatment of chronic renal failure. 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 [28]; however, it had new features. The catheter was provided with a polyester 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 could tie the peritoneum tightly [40]. These innovations by themselves did not decrease leakages until the implantation technique was modified. Instead of implantation through the linea alba, the catheter was inserted though the rectus muscle [40]. After implantation the flange was situated on the posterior rectus sheath, the deep cuff in the rectus muscle and the purse string was placed through the posterior rectus sheath, transversalis fascia, and the peritoneum.

Infusion or Pressure Pain

Some patients experience pain at the tip of the catheter with the straight intraperitoneal segment. This pain is partly related to a 'jet effect' of the rapidly flowing dialysis solution and to the pressure of the straight catheter tip. Catheters with a coiled intraperitoneal segment, as in the Palmer catheter [19], are less likely to induce abdominal pain 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. Many of the currently used catheters include this feature.

External Cuff Extrusion

The simplest way to avoid external cuff extrusion is not to use it; however, a single cuff catheter is associated with more exit/tunnel infections, higher peritonitis rates, and shorter survival [41–44]. Another remedy would be to locate the external cuff far away from the exit so it would be impossible to have it extruded; however, a long sinus tract (from the exit to the cuff) creates a situation similar to the single cuff catheter predisposing to exit/tunnel infections. A localization of the cuff close to the exit predisposes to its extrusion. There are at least two forces favoring cuff extrusion: (1) the pushing force of catheter resilience and (2) pulling and tugging on the catheter. The resilience (shape memory) of the straight catheter implanted in an arcuate tunnel plays the most important role in cuff extrusion.

As a compromise between the requirements of a short sinus tract to prevent infections but not so short to favor cuff extrusions the cuff should be implanted approximately 2–3 cm beneath the skin. Moreover, resilience forces should be eliminated by designing the catheter in a shape similar to the shape of the tunnel. To follow original Tenckhoff recommendations that the catheter should be implanted with an arcuate subcutaneous tunnel with downward directions of both intraperitoneal and external exits, the catheter should have a permanent bend between the cuffs. The catheters with such a bend are called swan-neck catheters [45]. Similar principles were applied by Cruz to polyurethane catheters [46].

Double-Lumen Catheters for Continuous Flow Peritoneal Dialysis

Continuous flow peritoneal dialysis, introduced in 1925 by Rosenak and Siwon [2], was used concomitantly with intermittent flow peritoneal dialysis until the late 1960s. High fluid flows were used with either two catheters [47] or double-lumen catheters [48]. The method was abandoned in the 1970s as associated with technical difficulties due to catheter obstruction, abdominal pain related to high flow, and less than expected dialysis efficiency because of fluid channeling [49].

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 [50]. 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. Internally 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 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. [51]. 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. In vitro studies showed excellent flow characteristics and very low recirculation [51].

Clinical trials are needed to determine whether continuous flow peritoneal dialysis can be revived after more than a quarter century hiatus.

Most Commonly Used Chronic Peritoneal Catheters

Straight and Coiled Tenckhoff Catheters

The catheters consist of the silicone rubber tubing with a 2.6-mm internal diameter and 5-mm external diameter. 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: intraperitoneal about 15 cm, intercuff 5–7 cm, and external 16 cm. The intraperitoneal segment has an open end and multiple 0.5-mm perforations on 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 distal 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. The catheters are manufactured by numerous companies.

Swan-Neck Catheters

The design of the swan-neck catheters is based on a retrospective analysis of complication rates with Tenckhoff and Toronto Western Hospital catheters. The 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 downward; however, the resulting arcuate tunnel led to frequent external cuff extrusion [45]. All swan-neck catheters feature a permanent bend between cuffs [45]. The catheter was dubbed 'swan neck' because of its shape. Because of this design, catheters can be placed in an arcuate tunnel in an unstressed condition with both external and internal

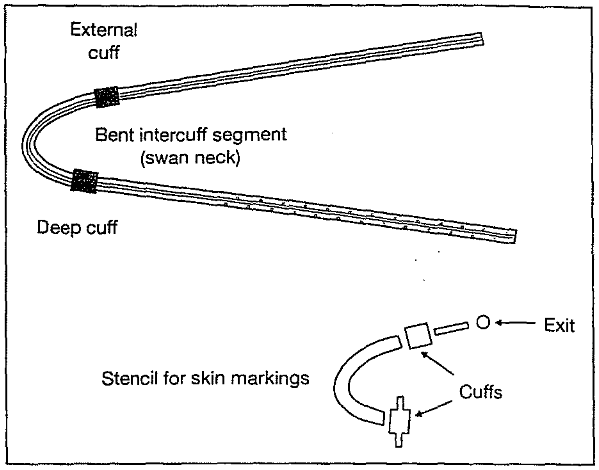

Fig. 1. Swan-neck Tenckhoff catheter with straight intraperitoneal segment and stencil for skin markings.

segments of the tunnel directed downward. The downward directed exit, two cuffs, and optimal sinus length reduce exit/tunnel infection rates. A permanent bend between cuffs eliminates the silicone rubber resilience force or the 'shape memory' which tends to extrude the external cuff. Downward peritoneal entrance tends to keep the tip in the true pelvis reducing its migration. Insertion through the rectus muscle decreases pericatheter leaks. Lower exit/tunnel infection rates curtail peritonitis episodes. Finally, swan-neck catheters with a coiled intraperitoneal segment minimize infusion and pressure pain. Several types of swan-neck catheters are available [52]. Swan-neck catheters are designed to have an exit in the abdominal integument (swan-neck abdominal catheters, fig. 1, 2) or in the chest (swan-neck presternal catheter, fig. 3). Stencils have been developed for skin markings to facilitate creation of proper tunnels for swan-neck catheters (fig. 1, 2). 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.

Swan-Neck Abdominal Catheters

Swan-neck abdominal catheters are one of the most commonly used catheters at present. According to the manufacturer (Kendal Healthcare, Mansfield, Mass., USA), over 17,000 swan-neck abdominal catheters were sold worldwide in 2002. Long-term studies from a number of peritoneal dialysis programs reported lower complications and better survival of swan-neck catheters compared to other catheters [53–57].

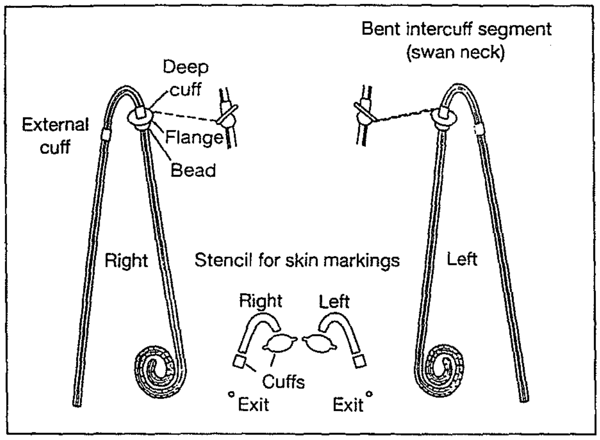

Fig. 2. Swan-neck Missouri catheters and stencils for right and left tunnels. The flange and bead are slanted 45°; once the catheter is properly implanted, the intraperitoneal tubing is directed downward to keep the tip in the true pelvis.

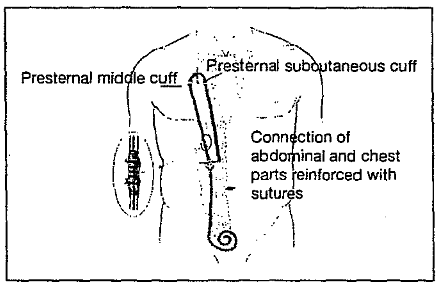

Fig. 3. Implanted swan-neck presternal peritoneal catheter in relation to torso.

Swan-Neck Tenckhoff Straight and Coiled. The Tenckhoff type of the swan-neck peritoneal dialysis catheter (fig. 1) 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; however, a subcutaneous 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.

Swan-Neck Missouri Straight and Coiled. The swan-neck Missouri catheter has a flange and bead circumferentially surrounding the catheter just below the internal cuff, similar to the TWH-2 catheter [40]; however, the flange and bead are not perpendicular but slanted approximately 45° relative to the axis of the catheter (fig. 2). The slanted flange and bead, and bent tunnel segment require that the swan-neck Missouri catheters for right and left tunnels be mirror images of each other. To facilitate recognition of right and left Missouri catheters, the tubings have a radiopaque stripe in front of the catheter. It is imperative to implant the catheter with an appropriate tunnel direction, otherwise the catheter will not provide any advantages, and rather worse results may be encountered. The intraperitoneal segment may be straight or coiled.

Moncrief-Popovich Catheter. This catheter is a modified swan-neck Tenckhoff coiled catheter with a longer subcutaneous cuff (2.5 cm instead of 1 cm). It is most commonly used in conjunction with the Moncrief-Popovich implantation technique, whereby the external part is kept under the skin until the ingrowth of the tissue into the cuff is strong. Only after several weeks (3–6 or more), is the external part exteriorized [58].

Swan-Neck Presternal Catheter

The idea of a presternal exit location stemmed from several observations indicating that this location may decrease exit infections [59]. 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 decreases chances of contamination. Moreover, a loose garment is usually worn on the chest and there is less pressure on the exit. Clinical surgical experience indicates that wounds heal better after thoracic surgery than after abdominal surgery; this may be related to less chest mobility or some other reasons. Obese patients have higher exit site infection rates and a tendency to poor wound healing, particularly after abdominal surgery. The subcutaneous fat layer is several times 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. The catheter is particularly useful in obese patients (body mass index > 35), patients with ostomies, children with diapers and fecal incontinence, and patients who want to take tub bath without the risk of exit contamination. Many patients prefer presternal catheter because of better body image.

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 Missouri coiled catheters, minimizing catheter obstruction, cuff extrusion, pericatheter dialysate leak and infusion pain. A major difference from the swan-neck Missouri catheter is in the length of the subcutaneous tunnel.

The presternal peritoneal dialysis catheter is composed of two flexible (silicon rubber) tubes, which are connected end to end at the time of implantation (fig. 3). The implanted lower (abdominal) tube constitutes the intraperitoneal catheter segment and a part of the intramural segment. The upper or chest tube constitutes the remaining part of the intramural segment and the external catheter segment. The lower tube is identical to the swan-neck 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 coupled with the distal part of the upper or chest part at the time of implantation. The connection is reinforced with sutures placed over the connector grooves on both the abdominal and thoracic tubes. Details of the catheter implantation technique have been recently published [59].

Ten years of experience with this catheter confirmed theoretical predictions. The results regarding infectious complication and catheter survival were superior to other catheters, including swan-neck abdominal catheters [59]. Their use has gradually been increasing in recent years; according to the manufacturer (Kendal Healthcare, Mansfield, Mass., USA), 217 catheters were sold worldwide in 2000, 386 in 2001, and 371 in 2002.

Disadvantages of the presternal catheter are minimal. Compared to abdominal catheters, dialysis solution flow is slightly slower due to the increased catheter length; however, the slower flow is insignificant clinically. There is a possibility of catheter disconnection in the tunnel but this complication is extremely rare in adults and easily corrected. Finally, the implantation technique is more challenging compared to that of single-piece, abdominal catheters. This may be one of the reasons of limited use. A video showing the implantation technique in detail is available from the manufacturer.

Concluding Remarks

The Tenckhoff catheter, developed in 1968, continues to be widely used for chronic peritoneal dialysis, although its use is decreasing in favor of swan-neck catheters. Soft, silicone rubber instead of rigid tubing virtually eliminated early complications such as bowel perforation or massive bleeding. Other complications, such as obstruction, pericatheter leaks, and superficial cuff extrusions, have been markedly reduced in recent years, particularly with the use of swan-neck catheters and insertion through the rectus muscle instead of the midline. However, complications still occur so new designs are being tried. A renewed interest in continuous flow peritoneal dialysis stimulated inventions of imaginative, double-lumen catheters.

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