Published in final edited form as:

J Invest Surg. 2019 June ; 32(4): 321–330. doi:10.1080/08941939.2017.1421731.

Preliminary Evaluation of the Viability of Peritoneal Drainage Catheters Implanted in Rats for Extended Durations

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Abstract

Purpose/Aim—In developing a novel peritoneal oxygenation therapy, catheters implanted into the peritoneal cavity became obstructed with omental tissue and prevented the infusion and removal of fluid from the peritoneal cavity. The obstruction of peritoneal catheters is a significant failure in researching various peritoneal treatments as further fluid administration is no longer possible. The purpose of this preliminary study was to determine the most effective catheter design for infusion and removal of fluid into the peritoneal cavity of rats.

Materials and Methods—Four types of catheters were tested including the Jackson-Pratt, round fluted drain, flat fluted drain, and an original design. Three of each catheter type were surgically placed into the peritoneal cavity of rats ($n = 12$). In order to test the efficacy of each catheter, saline was infused and extracted twice daily. Catheters were scored on a weighted scale based on the amount of time they remained patent, the subjective force needed for extraction/infusion, and the amount of saline removed.

Results—The round and flat fluted drain catheters remained patent for the full duration of the study (12 days) compared to the other models which failed after 7 days. These catheters also yielded a high average for extracted saline volume and an easy extraction/infusion.

Conclusions—The round and flat fluted drain catheters were recognized as viable options to be used in rats for peritoneal drain studies of up to 12 days.

Keywords

abdominal surgery; peritoneal drainage; catheter blockage; animal model; Jackson-Pratt; long term patency

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DECLARATION OF INTEREST

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

INTRODUCTION

The peritoneum is the largest serous membrane in the mammalian body and surrounds the abdominal cavity. The peritoneum supports the abdominal organs including the liver, stomach, and intestine while providing structure for the vasculature, lymphatics, and nerves of the organs.¹ Due to these functions, the peritoneal cavity and peritoneum are associated to important medical treatments and drug delivery.² Well known medical procedures performed requiring infrequent access through the peritoneal cavity include appendectomies, laparoscopic surgeries, and organ transplants. Intermittent drug delivery in laboratory rodents is also frequently performed through the peritoneal cavity because of the difficulty in delivery through intravenous access.³ Medical procedures that require repeated or continuous delivery of treatment to the peritoneal cavity include peritoneal dialysis, intraperitoneal cancer treatments, and peritoneal oxygenation.^{2,4-6} The rat animal model is often used to validate repeated and prolonged peritoneal treatments which are delivered into the peritoneal cavity with an implanted catheter. Although catheterization of the peritoneal cavity is a simple procedure, the two major risks of peritonitis and catheter failure may occur during long-term experiments. Peritonitis is the inflammation of the peritoneum caused by a bacterial or fungal infection and can be mitigated by strict adherence to sterile technique and proper maintenance of the implant incision.^{7,8} Other catheter failures occur when the catheter is displaced from the peritoneal cavity, the subcutaneous tissue becomes infected, or the catheter inlet becomes obstructed by tissue growth.^{6,8-10}

The unique environment and complex structure within the peritoneal cavity requires catheters specifically designed to remain viable while implanted. Several design features of peritoneal catheters limit the occurrence of catheter failures. The first feature is adding special surface treatments to the peritoneal catheters. For example, to prevent the displacement of the catheter, the length of the catheter that is subcutaneously tunneled may be coated with bioglass. The bioglass coating facilitates tissue adherence to the catheter tubing which supports its placement.¹¹ Additional surface treatments include silver and antimicrobial coatings to prevent infection and heparin to limit tissue obstruction at the catheter inlet.^{7,9,12} The current peritoneal catheter most commonly implanted for peritoneal dialysis is the Tenckhoff catheter, a loosely coiled tube which has multiple pores on the surface for fluid transport^{10,13,14} (Figure 1a). The multiple pores of the Tenckhoff catheter are designed to limit the risk that the fluid pathway can be obstructed by omental tissue wrapping around the catheter; however, the pores are still at risk from tissue ingrowth.^{10,14} An alternative design in peritoneal catheters used to prevent the incidence of tissue adhesion and obstruction employs external channels or flutes for fluid transport. Fluted catheters used for peritoneal dialysis and wound draining include the Ash Advantage and the Blake drain (Figure 1b and c).¹⁵⁻¹⁷ While these catheter designs have not been explicitly compared in rats, the Tenckhoff catheter design has failed in dogs after 4 days while the fluted Ash Advantage was functional for up to 60 days.¹⁵

We are investigating a novel method of peritoneal oxygenation which may provide an extra pulmonary option for treating lung failure with less inherent risk and higher survival rates than existing alternatives.^{4,5} Briefly, the technique used in our peritoneal oxygenation experiments is similar to peritoneal dialysis: a large bolus of liquid is injected into the

intraperitoneal space and then removed following a dwell period. The peritoneal catheter must remain patent for up to 12 days while the process of inject/dwell/remove is repeated. The rat is the preferred animal model for much of our work, but the usefulness of this model has been limited because the patency of the peritoneal catheters was stymied by tissue obstruction. Much of this obstruction appears to be due to omental ingrowth from activated omentum and foreign body response.^{18,19} For example, in unpublished pilot studies, the Jackson-Pratt catheter (JP-7, MILA International Inc., Florence, KY) was found to have the highest removal efficiency of fluid with no instances of obstruction for short durations after implantation. However, during extended implantation periods, all the Jackson-Pratt catheters implanted failed to remove fluid from the abdominal cavity after the implant surgery recovery period of seven days. Inability to remove the previous fluid bolus prevented administration of multiple treatments because the accumulated volume and pressure posed a risk to the animal.^{20–22} After the rats were euthanized, the abdomens were opened and the catheters inspected revealing that the pores of the Jackson-Pratt catheters had become completely in-grown and obstructed with omentum, fat, and fascial tissue. We speculate that the porous structure of the Jackson-Pratt catheter may have served as a scaffold for cell and tissue growth.^{23,24}

An optimal catheter will either prevent or overcome the tissue growth obstructing the catheter while dwelling in the cavity. Other than our preliminary work, to the best of our knowledge, there is no prior work that overcomes the problem of catheter patency for durations between 7 and 21 days of infusion and draining from the rat IP space. Thus, the objective of this pilot study is to identify or design a more effective catheter for prolonged infusion and removal of fluids from the peritoneal cavity. The most effective catheter will be determined by implanting catheters of various designs into the peritoneal cavity of rats and measuring the duration and quantity that saline is successfully infused and removed. We will also assess how effective the designs were at preventing and overcoming tissue obstruction. Discovery of an effective catheter will enable us to perform trials for evaluating intraperitoneal treatments in rats with a planned duration of 14–21 days.

MATERIALS AND METHODS

All animal studies were performed in accordance with the University of Nebraska-Lincoln, Institutional Animal Care and Use Committee. Male Wistar rats ($n = 12$, $m = 551.9 \pm 0.2$ g) were housed individually with free access to food and water. The animals were randomly assigned housing by the animal facility staff and allowed to acclimate 4 days before the study. It was previously observed that omental ingrowth into the peritoneal catheter was consistent and wholly disruptive, preventing drainage of the intraperitoneal fluid. Due to this consistency, a sample size of three rats per group would be adequate for a preliminary study in differentiating catheter effectiveness.

Rats were randomly implanted with one of four peritoneal lavage catheter types (Figures 2 and 3). Each rat had the catheter surgically implanted and routed subcutaneously to its back. The catheter types were: Jackson-Pratt catheter (JP-7, MILA International Inc., Florence, KY), a 15 French round fluted catheter (072188, Bard Medical, Covington, GA), a 7 mm flat three-fourth fluted catheter (072210, Bard Medical, Covington, GA), and a catheter of

custom design. Though the Jackson-Pratt catheters failed in earlier pilot studies,²⁵ further trials implanting Jackson-Pratt catheters were performed to confirm the exact duration they remained functional and the cause of their failure. All catheters were trimmed to allow for 10 cm of tubing to be within the peritoneal cavity.

Custom Drain Catheter Design

The purpose behind this design was to mimic T-fluted catheters which exhibited high efficiencies at fluid removal from studies of peritoneal dialysis in dogs and humans.^{15,16} The flutes provide an external path for capillary movement along the outside of the catheter rather than an internal path.²⁶ The goal of fluted catheter designs is to provide a large surface area for fluid to flow and that must be blocked by tissue before flow can be obstructed. The original design was comprised of 4 lengths of 2 mm outer diameter tubing (EW-06449-10, Cole Parmer, Vernon Hills, IL) twisted around each other in a helical pattern and secured at 3.2 cm (1.25 in) intervals with narrow segments of heat shrink tubing (HS-ASST-9, NTE Electronics, Inc., Bloomfield, NJ) (Figure 3). The twisting tightened the segments together and increased the rigidity of the catheter much like a braided rope. The custom design replicated the function of flutes by creating grooves between the segments of tubing. The custom design was also created to allow for an inexpensive alternative that could be easily manufactured on site. The custom design was then compared against fluted catheters similar to those found in successful peritoneal dialysis of dogs and that are commercially available.

Surgical Procedure and Implantation of Catheters

Rats were anesthetized in an induction chamber with 5% isoflurane and maintained on 2% isoflurane during the surgical procedure. Each animal was weighed and placed in the supine position on a warming pad (Gaymar T/pump Classic, Stryker Corporation, Kalamazoo, MI) set at 38 °C for maintenance of body temperature. After the animal was fully sedated and unresponsive to paw pinches, the back and left lateral abdomen was shaved and sterilized. A small incision was made on the left lateral abdomen to expose the peritoneal cavity where a randomly selected catheter was then inserted into the cavity (Figure 4a). The fascia was stitched around the catheter with a purse-string suture to prevent the catheter from sliding out during the study.^{27–29} The rat was then rolled on to its right side, and a small incision was made into the skin at the upper back. The catheter was subcutaneously routed through this opening and any extra length was trimmed so the end of the catheter was even with the back incision (Figure 4b). An access port on the back was made by connecting the catheter end with a luer elbow fitting (EW-45502-84, Cole-Parmer, Vernon Hills, IL). The fitting was sutured in place to the back under the skin and closed off with a male luer lock cap (51525K38, McMaster-Carr, Elmhurst, IL). Both the luer elbow fitting and lock cap were cold sterilized for 20 min in glutaraldehyde plus and rinsed with sterile saline before they were placed in the rat. The incisions on the abdomen and back were closed after pain medication was administered with a 1 mL slip-tip syringe through the abdominal incision to the subcutaneous tissue surrounding the implanted catheter. We used buprenorphine SR (1.2 mg/kg, Buprenorphine SR, Zoopharm, Windsor, CO) for 3 days to alleviate pain from the abdominal incision and the implanted catheter. If the rat displayed signs of distress or pain 4–7 days after the surgery, it would have been given an additional buprenorphine dose. No

rats required the second dose of buprenorphine. If complications in the catheter implantation occurred (catheter slipping, re-opening of the incisions, etc.), the rat was withdrawn from the study. After closing the incisions, sterile saline (15 mL) was injected directly into the peritoneal cavity with a syringe connected to tubing (6516T43, McMaster-Carr, Elmhurst, IL) and a barbed luer fitting (51525K33, McMaster-Carr, Elmhurst, IL). The rat was then allowed to recover from anesthesia and was returned to its home cage.

Testing and Evaluation of the Catheters

The efficacy of the catheters was determined by an infusion/extraction procedure developed to analyze the ease of function (i.e., subjective draw force of the plunger), the volume of saline that could be extracted, and the duration a catheter remained patent. These assessments were performed every 12 h for 12 days. The initial procedure started with an infusion, a 12-h “long dwell” period, and the extraction and measurement of the previously injected saline. The removed volume was termed “long dwell extraction.” Next, 15 mL of fresh sterile saline was infused, immediately extracted, and the extracted volume measured. The removed saline volume was termed “short dwell extraction.” Finally, the saline extracted for the “short dwell” was reinfused for the 12-h “long dwell” of the next sampling period.

The effectiveness of each catheter was scored by three weighted criteria: extraction volume after a long dwell, ease of function, and time the catheter remained patent. The extraction volume was measured and scored every 12 h after 15 mL was infused and dwelling in the cavity for the entire duration of the study. The long dwell extraction was not performed at the sample period 12 h immediately after surgery to allow time for the animal to recover from the surgery. At each sample period a maximum volume of 12 mL could be extracted after a long dwell and contribute to a maximum of 12 points (1 point per mL). The “extraction performance” of the catheter was then determined to be out of a maximum score of 276 points (11.5 days $\times$ 2 samples daily $\times$ 12 mL possible to be extracted). The second scoring criterion was “ease of function” and was a subjective measure of the difficulty to draw back the plunger of a syringe to extract saline from the peritoneal catheter and was scored on a scale of 1–4 points scored as follows: (1) drawing back the plunger was difficult with no fluid removed; (2) drawing the plunger was moderately hard with little fluid removed; (3) the plunger was drawn moderately easily; (4) the plunger draw was easy. The “ease of function” score was out of a maximum 96 points (12 days $\times$ 2 samples daily $\times$ 4 points). The final criterion of scoring the catheters was the time the catheter remained patent. Each day of patency represented one point with 12 points maximum if the catheter was patent for the entire study. If the catheter failed to remove saline during three consecutive short extractions (36 h), the catheter was deemed not operable, potentially occluded, and resulted in the end of the study for the test subject. The scoring criteria were weighted so that each contributed equally to the final efficiency score (288 points each, 864 points total). The following scoring equation was used to normalize the scores on a scale of 0% to 100%:

$$\text{Catheter Efficiency} = \frac{(\sum \text{Extracted Volumes}) + (3 \times \sum \text{Ease Scores}) + (24 \times \text{Time Patent})}{864} \times 100$$

Short dwell extraction amounts were recorded but not used in ranking each catheter. The short dwell measurement simply provided an instantaneous indication of how well the catheter was working at the moment. The measurement of short dwell extraction was also used to determine the end point of a catheter. The lack of ability to extract liquid in the short term dwell for 3 testing periods (36 h) indicated the catheter was not operable and potentially occluded resulting in the conclusion of the study for the catheter.

End Points and Necropsy

End points for the observation of each animal were at the conclusion of 12 days or as indicated by 3 consecutive periods where the short term extraction volume of saline was zero. The study also ended if the catheter was dislodged from the back incision either from rat moving or the incision re-opening. The open wound from the incision site can cause pain and infection requiring the animal to be withdrawn. At the end of the study, the rats were euthanized by carbon dioxide inhalation following IACUC procedure guidelines. After death, the abdomen was opened by creating an incision along the medial plane. The catheter was removed from the cavity with care taken not to detach any tissue adhered to or obstructing the catheters. Images were taken of the catheters within and removed from the cavity.

Statistics

All numbers are written as mean $\pm$ standard deviation. Analysis of variance (ANOVA) with separate means followed by the Tukey multiple comparison test was performed on efficiency scores to test for any differences between groups. All tests used the same level of significance ($\alpha = 0.05$).

RESULTS

The purpose of this pilot study was to design and evaluate catheters which could provide reliable peritoneal infusion and extraction of liquid volumes for a study in rats with a duration of 10–14 days. The highest duration of patency was the flat fluted drain which remained patent the full 12 days (Figure 5). The flat drain was followed by the round fluted drain which remained patent 11.5 ± 0.6 days. Observation was stopped early on day 11 because the 15 mL of saline for the short dwell extraction could not be infused. Instead, the saline began leaking during the infusion from the incision where the catheter was fixed to the back. The Jackson-Pratt and custom catheter had the lowest duration of patency at 7 ± 0.3 and 6 ± 1.5 days, respectively. All three Jackson-Pratt drains were dropped from the study early (days 6.5 and 7) due to having no extraction volume after the short term dwell for three consecutive sample times. Two custom catheter trials ended early due to leaking around the back incision during saline infusion with one of them being unable to infuse any saline. The third custom catheter was dropped because three consecutive short dwell extractions of saline were zero.

The flat fluted drain had the highest score for ease of function (i.e., the subjective draw force of the plunger) with an average of 3.0 ± 0.6 out of a maximum score of 4 during the time it was patent. The remaining catheter scores for ease of function were very similar with the

round fluted drain at 2.0 ± 0.7 , the Jackson-Pratt at 2.0 ± 0.8 , and the custom design at 2.0 ± 0.5 . Over the 12-day period all but the flat fluted drain experienced a decreased score in the mean ease of function (Figure 6).

The flat fluted drain achieved the highest average volume of saline extracted after a short dwell with 8.3 ± 2.0 mL. The round fluted drain came second with 7.1 ± 2.7 mL of saline extracted after the short dwell. The Jackson-Pratt extracted 6.1 ± 4.5 mL while patent and the custom design extracted 4.4 ± 2.1 mL after the short dwell period. The average of short dwell extraction volume increased in the flat fluted drain as the study progressed while all other catheters extracted less saline over time (Figure 7). On day 7, the Jackson-Pratt and custom catheters removed zero milliliters of saline.

The catheter with the highest average volume of fluid extracted after a long dwell period was the flat fluted drain with 2.4 ± 1.9 mL. The following highest amount extracted after a long dwell period was the round fluted drain with 1.2 ± 1.2 mL. The custom design extracted 0.3 ± 0.3 mL, while the Jackson-Pratt extracted the least volume of fluid at 0.1 ± 0.2 mL after the long dwell period. Four days after the catheters were placed, the Jackson-Pratt and custom catheters could not extract an average volume above 1 mL after the long dwell of 12 h (Figure 8), while the round fluted drain experienced an increased extraction volume until day 8 and the average extraction volume from the flat fluted drain increased until the end of the study.

Overall, the flat fluted drain had the highest efficiency at $63.8 \pm 13.2\%$ derived from the weighted scoring (Figure 9). The catheter with the second highest weighted score was the round fluted drain with an efficiency of $56.3 \pm 4.0\%$. The third highest score was the Jackson-Pratt with $29.4 \pm 4.4\%$ while the lowest scoring catheter was the custom design at $24.2 \pm 8.85\%$. The efficiency of the two fluted catheters was significantly greater than the Jackson-Pratt and the custom catheter ($p < .05$).

The excised catheters revealed the degree of tissue growth and obstruction. The pores of all Jackson-Pratt catheters were completely obstructed by ingrowth of omentum, fat, fascia, and organ tissue (Figure 10a). The tissue was found to be strongly attached to the surface and pores of the Jackson-Pratt catheter. The flat and round fluted drains were partially surrounded by a fibrotic capsule (Figure 10b and c). The fibrotic capsule was highly vascularized and was integrated with, and attached to any nearby organs such as the liver, intestine, or colon. However, the flutes of the flat and round drains were never fully occluded by tissue and in fact the catheter could easily be pulled out of the fibrotic capsule with little to no tissue actually adhered to it. When the custom catheter was removed from the peritoneal cavity, the tubing segments had to be unraveled (Figure 10d). Omental and fibrotic tissue had grown between the tubing, separating the segments. Tissue growth was focused predominately around the heat shrink bands which bound the tubing segments of the custom catheters together.

DISCUSSION

The purpose of this preliminary study was to design or discover a catheter which remains patent while in the peritoneal cavity of a rat for approximately two weeks. The custom catheter was the lowest scoring with an average of $29.6 \pm 14.5\%$. Duration of patency was 5.7 ± 1.5 days with low long dwell extractions (0.27 ± 0.25 mL) and a low ease of function score (1.8 ± 0.5). The low score was attributed to the omental tissue growing between the tubing and pushed apart the braided structure and compromising the flow of fluid through the grooved flutes. Also, the tissue seemed to grow and attach specifically on the heat shrink material indicating it may have had a surface properties conducive to cell growth and adherence (Figure 10d). Thus, the custom design functioned to a limited degree, but requires several alterations to be a more effective catheter. For example, the braided tubing segments showed minimal tissue adherence, so they do not require a change of tubing material. However, the heat shrink which bound the segments requires replacement with a permanent method of binding or fusing the tubing together. The custom design can be improved in future iterations by addressing these issues.

The fluted drains were chosen for evaluation because of the success attributed to other catheters with flutes or channels on the exterior face when implanted in the peritoneal cavity.^{15–17} The shape and profile of the flat drain was the similar to the Jackson-Pratt with the difference being fluid flow of the Jackson-Pratt was facilitated by internal pores instead of external channels. The principle of the fluted design is to prevent tissue from being able to block the fluid inlets and create a large surface area for fluid to flow.^{15,16,26} The fluted design principle was highly successful in the rat peritoneal cavity as the two fluted drains had the significantly highest scores of the established criteria and overall efficiencies (Figure 9). Another property of the fluted catheters that attributed to their effectiveness was the minimal tissue adhesion and obstruction to the catheter surface (Figure 10). Minimal adhesion on the fluted catheters was likely because the surface was hydrophobic enough for water, saline, and blood to bead off the catheters even after implanted in the peritoneal cavity for 12 days.³⁰ In contrast, the surface of the Jackson-Pratt catheters is not hydrophobic before or after implantation.

Comparatively, the principle of the Jackson-Pratt catheter is having a large quantity of inlets and outlets with pores on the catheter surface. The large number of pores reduces the potential risk that the inlet would be obstructed. However, we believe the principle fails within the peritoneal cavity as the pores possibly act as a scaffold that facilitates cell and tissue ingrowth into the interior of the catheter.^{23,24,31} The short dwell extractions were very high to start out, but quickly decreased over time due to the pores of the catheter becoming blocked by tissue obstruction (Figure 9a). The liver was also found to have grown into the pores of two Jackson-Pratt catheters as they settled within the cavity near the liver after implanted.

Another possible hindrance to the performance of catheters was the formation of a fibrotic capsule which almost completely surrounded the fluted catheters. The encapsulation of the catheters was indicative of a strong foreign body response triggered by the implanted catheter and activating the omentum to increase the expression of vascularization, growth,

and healing factors.^{18,32,33} If omental tissue completely surrounded the entire catheter in a fibrotic capsule, the infused liquid could not readily flow out. The catheter encapsulation is a possible explanation to the high volumes of liquid able to be extracted in the short dwell with the fluted catheters, but the low amounts extracted in the long dwell. In the short dwell, the capsule possibly prevented infused saline from diffusing throughout the cavity, but instead remained localized in the fibrotic capsule so it could be readily removed. The saline filled capsule could also affect the stability of the catheter routed through the back and exposed outside the body. Once the pocket was full of liquid, any more perfusate being introduced through the catheter would cause overflow through the abdominal seal and back incision. Fluid leaking from the back access port was observed in several occasions during testing and may have compromised the ability of the skin to heal properly around the catheter allowing it to slide out of the incision site. Also, after a long dwell, the tissue of the fibrotic capsule could be aspirated into the catheter preventing fluid flow. Another possibility for the large removal volume between long and short dwells is significantly more saline was absorbed by the peritoneum than the estimated 3 mL during the 12-h dwell.^{34–36} A greater absorbed volume of saline would result in the maximum volume of 12 mL never being able to be extracted artificially decreasing the weighted score and the catheter efficiency. These phenomena could account for the low overall amounts of saline able to be withdrawn from any catheter design after a long dwell as all values were less than 9 mL throughout the study.

A limitation of the pilot study was that the performance of the catheters may not have been accurately assessed due to issues with the catheters after implanted. One round fluted drain and two custom catheters were removed from the study early due to the incision on the back reopening (Figure 5). In these cases, the catheter became loose from the suture securing it to the back and a length of the catheter would extend out and retract in as the rat would move. The open wound and movement of the catheter caused noticeable discomfort to the animal. The movement of the catheter could have dislodged a portion of it from the peritoneal cavity and contributed to the leaking of saline from the back incision when infused into the catheter. A dislodged catheter could have decreased the weighted score and efficiency of the catheter. In future implants of the catheters, the back incision should be closed more securely and the elbow of the catheter access port should be fixed to the subcutaneous tissue below the incision. During implantation, the catheter should not be stretched from the peritoneal to the back incision tightly which will allow for the rat to have less restricted movement and decreased tension on the suture, skin, and fascia from the catheter moving. Another limitation of this study is that only one infusate, saline, was used to test the peritoneal catheters. Saline is a benign isotonic solution that the body can readily metabolize. Other infusates used for peritoneal dialysis, drug treatment, or oxygenation may not be as benign as saline and may influence tissue ingrowth and thus the patency and efficiency of the peritoneal catheter.

CONCLUSION

Substantial challenges in using a catheter implanted into the peritoneal cavity include tissue ingrowth, an aggressive foreign body response, and fixing the catheter in place. However, two suitable catheters were found for efficient delivery and removal of fluid into the

peritoneal cavity. The top two scoring catheters of the designs tested were the 15 Fr. round fluted drain and 7 mm flat three-fourth fluted drain which remained patent for 12 days, the longest observed duration, and had the highest average long dwell and short dwell extractions. The performance of the flat fluted drain is adequate for experiments in rats requiring multiple IP bolus infusions and drains over a period of 12 days. These fluted catheters will be utilized in future peritoneal oxygenation studies with planned duration of 14 days rather than the Jackson-Pratt design due to their long average time of patency. Because omental growth in the rat is more aggressive than in larger species, the two fluted designs might also be useful in other animal models (leporine, canine, or porcine) for studies concerning peritoneal infusion and removal of fluids in periods longer than 7 days. Further study is necessary to evaluate the use of catheters with fluids other than saline.

Acknowledgments

We wish to thank UNL's IACP staff who helped us in performing the procedures and for caring for the animals used in this study.

FUNDING

Funding for this work was provided by the National Science Foundation grant EEC-1263181 and the DHHS-NHLBI of the NIH under award number 1 R21 HL129144-01. The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH. Additional funding was provided by the University of Nebraska Biomedical Research Seed Grant No. 507 and the Nebraska Research Initiative Grant.

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FIGURE 1. Catheter designs commonly implanted into the peritoneal cavity (a) coiled Tenckhoff catheter, (b) Ash Advantage, and (c) Blake drains.

FIGURE 2.

Catheter types evaluated in the study (a) Jackson-Pratt, (b) round fluted drain, and (c) flat fluted drain and their respective cross-sections (d–f).

FIGURE 3.

(a) The custom catheter was constructed from four segments of tubing. (b–d) The segments were twist together to form a braid and binding together with heat shrink rubber. (e) The final length was 10 cm with an OD of 4.8 mm.

FIGURE 4.

(a) The placement of the peritoneal drain catheter into the peritoneal cavity of the rat. The catheter was secured to the fascia of the cavity to prevent movement. (b) The back of the rat with the adapter elbow inserted into the protruding end of the catheter and closed with a cap.

FIGURE 5.

The time in days each catheter design remained patent. Rats were censored (○) for saline leaking from the back incision or external catheter damage.

FIGURE 6.

The change in the ease of function for extracting fluid over time for each catheter design implanted in the peritoneal cavity.

FIGURE 7.
The change in short dwell extraction amounts of saline over time by each catheter design.

FIGURE 8.

Volume of saline extracted after 12-h dwell for each catheter design implanted in the peritoneal cavity.

FIGURE 9.

The efficiency of the peritoneal catheters tested and calculated from their weight scores.

*Significantly different from Jackson-Pratt and the custom catheters ($p < .05$).

FIGURE 10.

(a) Jackson-Pratt had fat and liver tissue ingrowth into and around the pores of the catheter. (b) The round drain catheter had tissue encapsulation, but did not fail unless the flutes were blocked. (c) The flat drain also had tissue encapsulation, but remained patent until the flutes were blocked. (d) The custom design had tissue encapsulation and growth between the tubes. Tissue also surrounded the heat shrink holding the tubes together.