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DETERMINANTS OF CATHETER LOSS FOLLOWING CONTINUOUS AMBULATORY PERITONEAL DIALYSIS PERITONITIS

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♦♦ ***Background:*** **Few patients are able to resume peritoneal dialysis (PD) therapy after an episode of peritonitis that requires catheter removal. PD catheter loss is therefore regarded as an important index of patient morbidity. The aim of the present study was to evaluate factors influencing catheter loss in patients suffering from continuous ambulatory PD (CAPD) peritonitis.**

♦♦ ***Patients and Methods:*** **We retrospectively reviewed 579 episodes of CAPD peritonitis from 1999 to 2006 in a tertiary-care referral hospital. Demographic, biochemical, and microbiological characteristics were recorded. Episodes resulting in PD catheter removal ($n = 68$; 12%) were compared by both univariate and multivariate analyses with those in which PD catheters were preserved.**

♦♦ ***Results:*** **The incidence of PD catheter loss increased as the number of organisms cultured increased ($p = 0.001$). Also, PD catheter removal was more likely to occur after peritonitis episodes with low serum albumin level ($p = 0.004$), those with long duration of PD effluent leukocyte count remaining above 100/μL ($p < 0.001$), those with concomitant tunnel infection ($p < 0.001$), those with concomitant exit-site infection ($p = 0.005$), and those with presence of catastrophic intra-abdominal visceral events ($p < 0.001$). Duration on PD preceding the peritonitis episode was of borderline significance ($p = 0.080$). On the contrary, initial PD effluent leukocyte count and serum level of C-reactive protein were not predictive of PD catheter loss. Micro-organisms of the Enterobacteriaceae family were the major pathogens responsible for PD catheter loss following polymicrobial peritonitis. Furthermore, we found that there was no association between polymicrobial peritonitis and the catastrophic intra-abdominal visceral event, although both resulted in a greater incidence of PD catheter loss. Among the single-organism group in our population, the microbiological determinants of PD catheter loss included fungi ($p < 0.001$), anaerobes ($p = 0.018$), and *Pseudomonas sp* (borderline significance: $p = 0.095$).**

♦♦ ***Conclusion:*** **PD catheter loss as a consequence of peritonitis is related primarily to hypoalbuminemia, longer duration of PD effluent leukocyte count remaining above 100/μL, the etiologic source of the infection, and the organism causing the infection. Peritonitis associated with concomitant tunnel or exit-site infections and abdominal catastrophes were more likely to proceed to PD catheter loss. The microbiological determinants of PD catheter loss in the present study included polymicrobial infections caused by Enterobacteriaceae as well as monomicrobial pseudomonal, anaerobic, and fungal infections.**

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KEY WORDS: Peritoneal dialysis catheter loss; peritonitis; CAPD; microbiology.

Peritonitis is the most important complication of long-term peritoneal dialysis (PD) therapy and causes significant morbidity and mortality (1,2). It is probably the most important cause of technique failure in PD (3,4). The majority of peritonitis can be treated successfully with intraperitoneal antibiotics alone, but the remainder require surgical removal of the PD catheter to eradicate the harbored micro-organisms (5). It has been suggested that single-organism peritonitis caused by fungi, *Pseudomonas sp*, Enterobacteriaceae, and *Staphylococcus aureus* is associated with a particularly poor outcome (4,6–10).

Catheter loss following an episode of peritonitis, as largely determined by the causative organism, results in difficulties for the patient to resume PD therapy (3,4,6,10–12). It interrupts the chosen form of dialysis and the patient has to be switched to temporary or even long-term hemodialysis therapy. Therefore, every

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effort should be made to maintain a well-functioning peritoneal access. We believe accurate classification of the etiologic source of infection, knowledge of biochemical parameters, and identification of the causative organisms at risk are helpful in guiding treatment strategies during an episode of peritonitis. At the same time, early recognition of patients that are likely to require catheter removal is also crucial. Otherwise, permanent peritoneal damage and even mortality may ensue.

In order to identify factors leading to PD catheter loss, we retrospectively reviewed peritonitis episodes over a 7-year period in patients on continuous ambulatory peritoneal dialysis (CAPD) in our PD unit. Patients that had their PD catheter removed due to peritonitis and those that had their PD catheter saved were analyzed.

PATIENTS AND METHODS

PATIENTS

All episodes of CAPD peritonitis in our PD unit between July 1999 and August 2006 were reviewed. Other modalities of PD such as automated PD were excluded from the analysis. There were two episodes of tuberculous peritonitis, and both resulted in PD catheter loss. They were excluded because of the small number of patients. Patients' demographic features and clinical parameters, including gender, cause of end-stage renal disease, comorbidities, age at the time of peritonitis, duration spent on PD preceding the peritonitis episode, serum albumin, serum C-reactive protein (CRP), PD effluent (PDE) leukocyte count (WBC), duration of PDE WBC remaining above 100/μL, regimen and duration of intraperitoneal antibiotic therapy, etiologic source of infection, and causative organism, were obtained.

Each episode of peritonitis was classified according to the following etiologies:

1. Touch contamination: any contamination resulting from technical inadvertence or error;
2. Post tubing change: any episode occurring within 3 days after PD catheter tubing change for noninfectious reasons;
3. Recurrent: an episode developing either within 4 weeks of the onset of the previous infection or within 2 weeks of antibiotics discontinuation;
4. Concomitant exit-site infection: concomitant presence of purulent discharge, with or without erythema, from the exit-site;
5. Concomitant tunnel infection: concomitant presence of erythema, swelling, and/or tenderness over the tunnel tract; the diagnosis was assisted by tunnel ultrasonography;
6. Diarrhea/constipation: an episode with prodromal or concurrent gastrointestinal symptoms of diarrhea or constipation;
7. Hematogenous: any episode when both blood culture and PDE culture yielded the same organism;
8. Abdominal catastrophe: an episode accompanied by intra-abdominal visceral injury;
9. Product defect: an episode resulting from any kind of product defect such as a broken PD bag or tubing;
10. Unknown etiology.

Peritoneal dialysis effluent was sent for cell count examination and culture when patients complained of abdominal pain or if the PDE was turbid. The diagnosis of peritonitis was based on at least two of the following: (1) abdominal pain or cloudy PDE; (2) WBC >100/μL PDE, with more than 50% polymorphonuclear cells; (3) positive smear or culture from PDE. Culture-negative peritonitis was defined as an episode that fulfilled the first two criteria but in which the PDE culture yielded a negative result; episodes with negative culture but with peritoneal eosinophilia (eosinophils >10% of total WBC and/or eosinophil count >100/μL) were excluded. Single-organism peritonitis was defined as an episode with only a single organism cultured. Polymicrobial peritonitis was defined as an episode with two or more organisms cultured.

Peritoneal dialysis effluent WBC was checked at the onset of peritonitis, and the frequency of follow-up was based on the patient's clinical manifestations. Duration of PDE WBC remaining above 100/μL was defined as the time gap between disease onset and the first time the PDE WBC declined to below 100/μL. In a few patients, PDE WBC rebounded and declined again, but it was not counted as part of the duration remaining above 100/μL. We must emphasize that the duration of PDE WBC remaining above 100/μL might be overestimated because it was not followed up on a daily basis. The initial serum level of CRP was checked within 3 days of disease onset. The peak serum level of CRP was the highest one recorded in the chart and might be underestimated because it was not routinely rechecked.

CLINICAL OUTCOMES

Peritonitis episodes were treated with the standard antibiotic protocol of our unit at that time. The regimens and durations of antibiotic therapy for individual patients were modified when culture results became available. Peritoneal dialysis catheters were removed and

patients were shifted to temporary hemodialysis when peritonitis failed to resolve with antibiotics alone. Because of the retrospective nature of our study, the indication for PD catheter removal was at the discretion of each physician. The clinical outcome at 3 months from the onset of peritonitis was reviewed for each case. There were 505 (87%), 53 (9%), 19 (3%), 1 (0.2%), and 1 (0.2%) patients that resumed PD, transferred to hemodialysis, died, received renal transplantation, or were lost to follow-up at 3 months after the peritonitis episodes, respectively. The overall technique failure rate was 9%. Among the 68 episodes requiring PD catheter removal, 13 (19%), 52 (76%), and 3 (4%) patients resumed PD, transferred to hemodialysis, or died by 3 months after the peritonitis episodes, respectively. Peritoneal dialysis catheters removed for other reasons, such as ultrafiltration failure, leakage, pleuroperitoneal communication, and following successful renal transplantation, were not included.

STATISTICAL ANALYSIS

Chi-square analysis or Fisher's exact test was used for comparison for categorical variables as appropriate. Continuous variables were compared by Student's t-test or one-way ANOVA as appropriate. Values of the continuous variables are presented as mean ± standard deviation unless otherwise specified. Such variables associated with PD catheter loss in univariate analysis with significance less than 0.10 were retained for multivariate analysis by logistic regression. The commercial program SPSS version 13.0 (SPSS Inc., Chicago, Illinois, USA) for Windows operating system (Microsoft Corp., Richmond, Washington, USA) was used for the analyses. All probabilities were two-tailed. A p value of less than 0.05 was considered statistically significant.

RESULTS

DEMOGRAPHIC CHARACTERISTICS AND CLINICAL PARAMETERS

Five hundred seventy-nine episodes of peritonitis were identified in 366 patients, for which full demographic, biochemical, and microbiological data were available. Characteristics of the study subjects are listed in Table 1. Fifty percent were male. Patients undergoing PD catheter removal had the same percentages of underlying renal diseases and comorbidities as those in whom the PD catheter was preserved.

Univariate analysis of PD catheter loss is listed in Table 2. Mean age at the time of peritonitis was 50 years. Catheter removal was not required in 511 episodes of peritonitis occurring in 312 patients, whereas 68 episodes of peritonitis requiring PD catheter removal were identified in 54 patients. In univariate analysis, variables associated with catheter loss included number of organisms cultured (p = 0.001), hypoalbuminemia (3.4 vs 3.7 g/dL, p < 0.001), duration of PDE WBC remaining above 100/μL (8.7 vs 4.8 days, p < 0.001), duration of intraperitoneal antibiotic therapy (16 vs 14 days, p = 0.002), concomitant tunnel infection (10% vs 1%, p < 0.001), concomitant exit-site infection (9% vs 3%, p = 0.017), and presence of abdominal catastrophe (9% vs 1%, p = 0.001). On the contrary, peritonitis episodes due to touch contamination were notably more likely to be resolved by antibiotic therapy alone in the absence of PD catheter removal (29% vs 47%, p = 0.006). While there was no significant difference in duration on PD, patients that required catheter removal tended to have received PD therapy for a longer period of time (mean 38 vs 31 months, p = 0.059). Peak serum level of CRP was also of borderline significance (p = 0.076), whereas initial serum level of CRP, initial PDE WBC, and regimen of intraperitoneal antibiotic therapy were not associated with PD catheter loss.

Determinants of PD catheter loss by multivariate analysis in all peritonitis episodes with different numbers of organisms cultured are listed in Table 3. Catheter loss was positively associated with the number of organisms cultured (p = 0.001), long duration of PDE WBC remaining above 100/μL (p < 0.001), concomitant tunnel infection (p < 0.001), concomitant exit-site infection (p = 0.005), and catastrophic intra-abdominal visceral events (p < 0.001), and negatively associated with serum albumin level (p = 0.004). Duration on PD preceding the peritonitis episode was of borderline significance (p = 0.080). Other parameters associated with PD catheter loss in univariate analysis, including duration of intraperitoneal antibiotic therapy, the etiologic source of touch contamination, and peak serum level of CRP, were not statistically significant using multivariate analysis.

Owing to the above findings, we further categorized the 579 peritonitis episodes into three groups based on the number of organisms cultured: culture-negative, single-organism, and polymicrobial infections accounted for 151 (26%), 401 (69%), and 27 (5%) peritonitis episodes, respectively. Patients of the three groups were similar in age, gender, and mean duration on PD at the time of peritonitis. There were no significant differences in etiologic sources of infection among the three groups of patients except that patients suffering from multiple-organism infection were more likely to experience prodromal or concurrent gastrointestinal symptoms of constipation or diarrhea (p = 0.031). Requirement of PD

TABLE 1
Demographic Characteristics of 366 Patients Retaining the Peritoneal Dialysis (PD) Catheter or Requiring PD Catheter Removal

	PD catheter			
	Preserved	Removed	Total	*p* Value
Patients (*n*)	312	54	366	
Gender (% male)	48	59	50	NS
Underlying renal disease				
Diabetic nephropathy	112 (36)	22 (41)	134 (37)	NS
Chronic glomerulonephritis	62 (20)	6 (11)	68 (19)	NS
Chronic interstitial nephritis	14 (5)	3 (6)	17 (5)	NS
Hypertensive nephrosclerosis	28 (9)	5 (9)	33 (9)	NS
Lupus nephritis	17 (5)	3 (6)	20 (5)	NS
Polycystic kidney disease	6 (2)	3 (6)	9 (3)	NS
Gouty nephropathy	5 (2)	2 (4)	7 (2)	NS
Obstructive nephropathy	5 (2)	1 (2)	6 (2)	NS
Unknown	30 (10)	5 (9)	35 (10)	NS
Previous chronic hemodialysis therapy	68 (22)	17 (32)	85 (23)	NS
Comorbidity				
Diabetes mellitus	118 (38)	24 (44)	142 (39)	NS
Coronary artery disease	39 (13)	6 (11)	45 (12)	NS
Cerebrovascular accident	21 (7)	2 (4)	23 (6)	NS
Malignancy	21 (7)	6 (11)	27 (7)	NS

NS = not statistically significant.
Values expressed as number of patients (percent) unless otherwise listed.

catheter removal was notably most frequent after polymicrobial peritonitis (30%), followed by single-organism peritonitis (12%), and was least common following culture-negative peritonitis (7%) ($p = 0.006$).

MICROBIOLOGY OF POLYMICROBIAL PERITONITIS

We identified 24 peritonitis episodes caused by two organisms. We found that all episodes leading to PD catheter removal involved two gram-negative organisms rather than two gram-positive organisms or one gram-positive plus one gram-negative organism. However, due to the small number of patients in this group, there was no statistically significant between-group difference. Culture results of the four episodes with two gram-negative organisms and catheter removal, including *Escherichia coli* plus *Klebsiella oxytoca*, *E. coli* plus *Enterobacter aerogenes*, *Enterobacter cloacae* plus *Pseudomonas aeruginosa*, and *Proteus vulgaris* plus *Morganella morganii*, showed predominantly members of the Enterobacteriaceae family.

CATHETER LOSS IN SINGLE-ORGANISM PERITONITIS

The species isolated from PDE of single-organism peritonitis are summarized in Table 4. In univariate analysis, the peritonitis episodes caused by *Pseudomonas sp* (10% vs 3%, $p = 0.044$), anaerobic organisms (6% vs 0.3%, $p = 0.006$), and fungi (27% vs 1%, $p < 0.001$) were significantly more common in patients that proceeded to PD catheter removal. In contrast, coagulase-negative staphylococci (CoNS; 4% vs 28%, $p < 0.001$), including *Staphylococcus epidermidis*, were associated with a significantly lower catheter loss rate than other organisms. Only 2 of the 99 episodes (2%) caused by CoNS resulted in PD catheter removal. These two episodes of CoNS peritonitis were both hospital acquired.

Table 5 lists determinants of PD catheter loss by multivariate analysis of single-organism peritonitis. Catheter loss was associated with duration on PD ($p = 0.031$), serum albumin level ($p = 0.029$), duration of PDE WBC remaining above 100/μL ($p < 0.001$), concomitant exit-site infection ($p = 0.024$), concomitant tunnel infection ($p = 0.001$), fungi ($p < 0.001$), and anaerobes ($p = 0.018$). Among single-organism peritonitis, abdominal catastrophes ($p = 0.052$) and pseudomonas ($p = 0.095$) infections were of borderline significance. Other parameters associated with PD catheter loss in univariate analysis, including CoNS infection, the etiologic source of touch contamination, and peak serum level of CRP, were not statistically significant using multivariate analysis.

TABLE 2
Characteristics of 579 Peritonitis Episodes Retaining Peritoneal Dialysis (PD) Catheter or Requiring PD Catheter Removal

	PD catheter			
	Preserved	Removed	Total	*p* Value
Total episodes (*n*)	511	68	579	
Age at time of peritonitis (years)	50±15 (16–83)	51±15 (18–78)	50±15 (16–83)	NS
Duration on PD (months)	31±28.6 (1–103)	38±35.0 (1–126)	32±29.5 (1–126)	0.059
Serum albumin (g/dL)	3.7±0.5 (1.9–5.0)	3.4±0.5 (2.0–4.5)	3.6±0.5 (1.9–5.0)	<0.001[b]
Serum C-reactive protein (mg/dL)				
Initial level (mg/dL)	8.48±7.10 (0.04–28.80)	9.08±7.11 (0.13–26.50)	8.55±7.10 (0.04–28.80)	NS
Peak level (mg/dL)	13.45±6.69 (0.26–34.60)	15.00±7.38 (2.60–42.10)	13.63±6.78 (0.26–42.10)	0.076
PD effluent leukocyte count				
Initial count (/μL)	2201±3539 (103–30800)	2243±3401 (125–20480)	2206±3520 (103–30800)	NS
Duration remaining above 100/μL (days)	4.8±4.2 (1–37)	8.7±6.3 (1–28)	5.3±4.6 (1–37)	<0.001
Initial first-generation cephalosporins	393 (77)	56 (82)	449 (78)	NS
Aminoglycoside usage	404 (79)	51 (75)	455 (79)	NS
Duration of intraperitoneal antibiotics (days)	14±4.8 (5–42)	16±10.1 (2–44)	14±5.7 (2–44)	0.002
Etiology				
Touch contamination	241 (47)	20 (29)	261 (45)	0.006[b]
Post tubing change	4 (1)	1 (2)	5 (1)	NS
Recurrent	48 (9)	8 (12)	56 (10)	NS
Concomitant exit-site infection	13 (3)	6 (9)	19 (3)	0.017
Concomitant tunnel infection	6 (1)	7 (10)	13 (2)	<0.001
Diarrhea/constipation	44 (9)	5 (7)	49 (9)	NS
Hematogenous	6 (1)	0 (0)	6 (1)	NS
Abdominal catastrophe	5 (1)	6 (9)	11 (2)	0.001
Product defect	7 (1)	0 (0)	7 (1)	NS
Unknown	137 (27)	15 (22)	152 (26)	NS
Number of organisms cultured (*n* = episodes)				0.001
0	140	11 (7%[a])	151	
1	352	49 (12%[a])	401	
2	18	6 (25%[a])	24	
3	1	1 (50%[a])	2	
4	0	1 (100%[a])	1	

NS = not statistically significant.
[a] Percentage of PD catheters removed among each group.
[b] Negative.
Values expressed as mean±SD (range) or number of episodes (percent) unless otherwise listed.

OUTCOMES OF PERITONITIS ASSOCIATED WITH ABDOMINAL CATASTROPHES

Table 6 summarizes the microbiological characteristics and clinical outcomes of peritonitis associated with abdominal catastrophes. The incidence (2%) was low but morbidity and mortality were high. None of the peritonitis episodes due to a catastrophic intra-abdominal visceral event in our subjects was polymicrobial in origin. We examined associations between clinical outcomes and all the variables in peritonitis episodes with abdominal catastrophes, including demographic features, biochemical parameters, type of abdominal catastrophe (3 episodes of cholecystitis and 5 episodes of bowel perforation, including 2 episodes of ruptured appendicitis), regimen and duration of antibiotic therapy, and culture result (5 episodes caused by Enterobacteriaceae and 2 episodes caused by anaerobes). Perhaps due to the small number of patients in this group, there was no statistical significance. We further analyzed the relationship between the PDE culture result and the type of abdominal catastrophe. We found that culture of an

TABLE 3
Determinants of Peritoneal Dialysis (PD) Catheter Loss by Multivariate Logistic Regression Analysis with Different Numbers of Organisms Cultured ($n = 579$)

Parameter	Odds ratio	95% CI	*p* Value
Duration on PD	1.01	0.99–1.02	0.080
Serum albumin level	0.45	0.26–0.78	0.004
Duration of effluent leukocyte count remaining above 100/μL	1.12	1.07–1.18	<0.001
Etiology			
Concomitant exit-site infection	4.75	1.61–14.00	0.005
Concomitant tunnel infection	10.84	3.26–36.08	<0.001
Abdominal catastrophe	12.61	3.37–47.09	<0.001
Number of organisms cultured	2.40	1.44–3.99	0.001

CI = confidence interval.

anaerobic organism in PDE was significantly associated with a catastrophic ruptured appendicitis ($p = 0.018$).

DISCUSSION

After an episode of peritonitis requiring catheter removal, the possibility of the patient resuming PD therapy is low (3,13). Among the peritonitis episodes requiring PD catheter removal in our study population, only 19% were able to resume PD. Medically intractable peritonitis warrants timely removal of the PD catheter to eradicate the infection; otherwise, unnecessary catheter removal should be avoided. Therefore, in order to facilitate judgment on treatment strategies, early recognition of patients at risk for PD catheter removal is important. The present study demonstrated that the requirement of PD catheter removal for peritonitis correlated positively with multiple infective organisms, duration of PDE WBC above 100/μL, concomitant tunnel infection, concomitant exit-site infection, and presence of abdominal catastrophes, and negatively with serum albumin level. Parameters associated with PD catheter loss in univariate analysis, including duration of intraperitoneal antibiotic therapy, the etiologic source of touch contamination, and peak serum level of CRP, were not statistically significant using multivariate analysis. Krishnan *et al.* (14) reported that the duration on PD and the duration of PDE WBC remaining above 100/μL were the only predictors of the outcome of an episode of peritonitis. However, in our study, duration on PD preceding the peritonitis episode was of borderline significance using multivariate analysis.

We demonstrated that the time gap between peritonitis onset and the first time the PDE WBC declined to less than 100/μL was independently predictive of catheter loss. The average duration of PDE WBC remaining above 100/μL in episodes retaining the PD catheter was 4.8 days, but was 8.7 days in those requiring catheter removal. Our findings are consistent with those of Krishnan *et al.* (14), who observed that the nonresolution rates of peritonitis were significantly higher if the PDE WBC remaining above 100/μL for more than 5 days. Chow *et al.* (15) recently demonstrated a significant association between the PDE WBC on day 3 and peritonitis outcome. They found that a cutoff PDE WBC of ≥1090/μL on day 3 carried a ninefold increased risk for catheter loss and death. Further prospective study could strengthen the predictive value of PDE WBC on treatment outcomes.

As an adverse prognostic factor, low serum albumin level predicts technique failure and death in patients on PD (16,17). Although the precise reason why hypoalbuminemia is associated with technique failure is unclear, Gulati *et al.* (17) proposed that it could be due to the fact that serum albumin is an inverse acute-phase reactant. Blake *et al.* (16) suggested that the association between hypoalbuminemia and adverse outcome in patients on PD is likely attributable to the underlying problem of malnutrition. However, in PD patients suffering from peritonitis, the relationship between serum albumin level and treatment outcome has been studied less extensively. Krishnan *et al.* (14) reported that serum albumin did not affect treatment outcomes. In contrast to their findings, we found that serum albumin level was negatively associated with catheter removal following peritonitis. However, since hypoalbuminemia, and not elevated serum CRP, was an independent predictor of PD catheter loss in the present study, factors other than inflammation should play a role during peritonitis. Nevertheless, the definitive explanation requires further investigations.

We also found that when fewer organisms were cultured, the PD catheters were less likely to be removed. Most culture-negative peritonitis is easily treatable without removal of the catheter. It may occur in patients that

TABLE 4
Characteristics and Microbiology of 401 Single-Organism Peritonitis Episodes Retaining the Peritoneal Dialysis (PD) Catheter or Requiring PD Catheter Removal

	PD catheter		PD catheter removal		
	Preserved	Removed	Total	rate (%)	*p* Value
Total episodes (*n*)	352	49	401		
Age at time of peritonitis (years)	51±14 (16–81)	51±15 (18–78)	51±14 (16–81)		NS
Duration on PD (months)	32±29.9 (1–103)	42±35.1 (1–120)	33±30.7 (1–120)		0.033
Serum albumin (g/dL)	3.7±0.5 (1.9–4.8)	3.4±0.5 (2.3–4.5)	3.7±0.5 (1.9–4.8)		0.001[b]
Serum C-reactive protein					
Initial level (mg/dL)	8.7±7.2 (0.07–28.8)	8.9±6.9 (0.13–26.5)	8.7±7.2 (0.07–28.8)		NS
Peak level (mg/dL)	13.1±6.3 (0.26–28.8)	15.1±7.4 (2.6–42.1)	13.3±6.5 (0.26–42.1)		0.041
PD effluent leukocyte count					
Initial count (µL)	2360±3661 (103–30800)	1977±2746 (137–15200)	2313±3561 (103–30800)		NS
Duration remaining above 100/µL (days)	4.7±3.9 (1–37)	9.0±6.8 (1–28)	5.2±4.6 (1–37)		<0.001
Initial first-generation cephalosporins	270 (77)	41 (84)	311 (78)		NS
Aminoglycoside usage	274 (78)	38 (78)	312 (78)		NS
Duration of intraperitoneal antibiotics (days)	14±4.8 (5–42)	16±9.2 (2–42)	14±5.5 (2–42)		0.024
Etiology					
Touch contamination	158 (45)	13 (27)	171 (43)		0.015[b]
Post tubing change	4 (1)	1 (2)	5 (1)		NS
Recurrent	46 (13)	8 (16)	54 (14)		NS
Concomitant exit-site infection	7 (2)	5 (10)	12 (3)		0.009
Concomitant tunnel infection	5 (1)	5 (10)	10 (3)		0.004
Diarrhea/constipation	31 (9)	3 (6)	34 (9)		NS
Hematogenous	5 (1)	0 (0)	5 (1)		NS
Abdominal catastrophe	4 (1)	5 (10)	9 (2)		0.002
Product defect	5 (1)	0 (0)	5 (1)		NS
Unknown	87 (25)	9 (18)	96 (24)		NS
Causative organism(s)					
Gram-positive bacteria					
Coagulase-negative *Staphylococcus sp*	97 (28)	2 (4)	99 (25)	2.0	<0.001[b]
Staphylococcus aureus	48 (14)	8 (16)	56 (14)	14.3	NS
Streptococcus sp	37 (11)	3 (6)	40 (10)	7.5	NS
Miscellaneous gram-positive bacteria	35 (10)	1 (2)	36 (9)	2.8	NS
Gram-negative bacteria					
Pseudomonas sp	12 (3)	5 (10)	17 (4)	29.4	0.044
Enterobacteriaceae family					
Escherichia coli	49 (14)	4 (8)	53 (13)	7.5	NS
Other Enterobacteriaceae[a]	27 (8)	5 (10)	32 (8)	15.6	NS
Miscellaneous gram-negative bacteria	41 (12)	5 (10)	46 (12)	10.9	NS
Anaerobes	1 (0.3)	3 (6)	4 (1)	75.0	0.006
Fungi	5 (1)	13 (27)	18 (5)	72.2	<0.001

NS = not statistically significant.
[a] Other Enterobacteriaceae include *Klebsiella sp*, *Enterobacter sp*, *Serratia marcescens*, *Proteus sp*, and *Citrobacter sp*.
[b] Negative.
Values expressed as mean±SD (range) or number of episodes (percent) unless otherwise listed.

self-medicated in response to recurrent episodes of peritonitis, and its clinical outcome is more favorable. On the other hand, multiple organisms on PDE culture indicate a higher risk of catheter loss. It has been suggested that polymicrobial peritonitis with enteric organisms often raises the suspicion that there is an underlying

TABLE 5
Determinants of Peritoneal Dialysis (PD) Catheter Loss by Multivariate Logistic Regression Analysis Among Single-Organism Peritonitis ($n = 401$)

Parameter	Odds ratio	95% CI	*p* Value
Duration on PD	1.01	1.00–1.024	0.031
Serum albumin level	0.43	0.20–0.92	0.029
Duration of effluent leukocyte count remaining above 100/μL	1.14	1.08–1.21	<0.001
Etiology			
Concomitant exit-site infection	5.44	1.25–23.61	0.024
Concomitant tunnel infection	11.09	2.71–45.41	0.001
Abdominal catastrophe	5.98	0.98–36.35	0.052
Causative organism			
Pseudomonas sp	3.08	0.82–11.52	0.095
Anaerobes	27.17	1.77–418.35	0.018
Fungi	28.76	9.06–91.24	<0.001

CI = confidence interval.

TABLE 6
Microbiological Characteristics and Clinical Outcomes of Peritonitis Episodes with Abdominal Catastrophe (Number of Patients = 11)

Age (years)	Gender	Abdominal catastrophe	Microbiology	Outcome
53	M	Ruptured appendicitis	*Bacteroides sp*	Catheter removed
61	M	Cholecystitis	No growth	Treated
72	F	Intestinal perforation	*Escherichia coli*	Catheter removed
43	F	Incarcerated umbilical hernia	No growth	Catheter removed, patient died
62	F	Perforated peptic ulcer	*Enterococcus sp*	Catheter removed, patient died
82	F	Perforated colon diverticulitis	*E. coli*	Patient died
41	F	Colon diverticulitis	*E. coli*	Catheter removed
55	F	Colon diverticulitis	*Proteus vulgaris*	Treated
50	M	Cholecystitis	*Enterobacter cloacae*	Treated
38	F	Cholecystitis	*Pseudomonas aeruginosa*	Treated
55	M	Ruptured appendicitis	*Bacteroides fragilis*	Catheter removed

gastrointestinal pathology as the cause of the peritonitis, and may indicate bowel perforation (18–20). In the present study, polymicrobial peritonitis posed the greatest risk of PD catheter loss compared with culture-negative and single-organism peritonitis. However, we observed that polymicrobial peritonitis did not necessarily indicate the presence of a catastrophic intra-abdominal visceral event. This is consistent with the results of other large single-center studies (21–25). Although controversy exists with respect to the association between polymicrobial peritonitis and abdominal catastrophe, timely evaluation by a surgeon should be carried out whenever an intra-abdominal pathology is suspected. Prompt catheter removal may save the peritoneum and increase the chance of resuming PD.

There were notably more prodromal or concurrent gastrointestinal symptoms of diarrhea and constipation in patients suffering from polymicrobial peritonitis. It has been reported that transmural migration of intestinal bacteria into the peritoneal cavity is facilitated in the presence of inflamed serosa resulting from constipation or diarrhea (26,27). Because of the retrospective nature of our analysis, we were not able to establish causality. Additionally, the microbiological features in the majority of polymicrobial episodes with PD catheters removed consisted of two gram-negative organisms, rather than two gram-positive organisms or one gram-positive plus one gram-negative organism. Micro-organisms of the Enterobacteriaceae family were the major pathogens responsible for PD catheter loss following polymicrobial peritonitis. Our findings reaffirmed the ISPD guidelines (28). Yip *et al.* (29) recently analyzed the risks and outcomes of peritonitis following flexible colonoscopy in CAPD patients. In their series, 5 episodes of peritonitis

developed following colonoscopy over a 13-year period. In our study population, however, no episodes of peritonitis occurred following colonoscopy.

Previous studies have shown that monomicrobial peritonitis caused by fungi, Enterobacteriaceae, *Pseudomonas sp*, and *Staphylococcus aureus* were associated with poor outcomes (4,6–10). Among the single-organism group in our study, organisms more frequently cultured in patients requiring PD catheter removal included *Pseudomonas sp*, anaerobic organisms, and fungi. *Staphylococcus aureus* should always be considered a potential pathogen. In agreement with other researchers (7–9), more than half of the PD catheter losses (57%) among single gram-positive organism-induced peritonitis in our population were attributed to *S. aureus* infections. Nevertheless, the proportion of *S. aureus* infections was similar among peritonitis episodes requiring PD catheter removal compared with those retaining the catheter. Choi *et al.* made a similar observation (13). In addition, we would like to highlight the serious nature of monomicrobial anaerobic peritonitis. Our findings are consistent with those of Szeto *et al.* (25), who observed that the presence of an anaerobic organism in PDE was associated with a marginally lower response rate to antibiotic therapy alone. Among peritonitis episodes with abdominal catastrophes in our study population, PDE culture of an anaerobic organism was significantly associated with ruptured appendicitis. It is our opinion that isolation of an anaerobe from the PDE is a clue to bowel perforation.

The duration of intraperitoneal antibiotic therapy was not associated with PD catheter loss in multivariate analysis in our study. There were three exceptional cases suffering from peritonitis with concomitant exit-site infection in our study population. Because of the fluctuating exit-site condition, intraperitoneal antibiotic administration along with exit-site care was performed for 44, 42, and 39 days, respectively. However, the clinical condition deteriorated eventually and all required catheter removal. After excluding these three episodes from univariate analysis, there was no association between duration of intraperitoneal antibiotics and catheter loss among the remaining 576 episodes ($p = 0.129$).

There are numerous clinical implications in the present study. Patients with hypoalbuminemia and longer duration of PDE WBC remaining above 100/μL were more likely to proceed to PD catheter loss, as were those associated with concomitant tunnel or exit-site infection and abdominal catastrophe. On the contrary, initial PDE WBC and serum level of CRP were not predictive of PD catheter loss. The result of PDE culture was also informative in predicting catheter loss. In our experience, more organisms being cultured denoted PD catheters were more likely to be removed. Although no connection was observed between abdominal catastrophe and polymicrobial peritonitis, the latter proceeded to catheter loss when multiple enteric pathogens were involved. Furthermore, pseudomonal, anaerobic, and fungal infections were associated with a greater rate of catheter loss among single-organism peritonitis. On the other hand, the clinical course of culture-negative peritonitis, as well as peritonitis caused by CoNS, tended to be more benign.

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