Microbiology and Outcome of Peritoneal Dialysis-related Peritonitis in Elderly Patients: a Retrospective Study in Hunan Province, China

Panai Song
Department of Nephrology, Second Xiangya Hospital, Central South University , Hunan Key Laboratory of Kidney Disease and Blood Purification, Changsha, Hunan

Dong Yang
Department of Nephrology, Second Xiangya Hospital, Central South University , Hunan Key Laboratory of Kidney Disease and Blood Purification, Changsha, Hunan

Jine Li
Department of Nephrology, Second Xiangya Hospital, Central South University , Hunan Key Laboratory of Kidney Disease and Blood Purification, Changsha, Hunan

Ning Zhuo
Department of Nephrology, Second Xiangya Hospital, Central South University , Hunan Key Laboratory of Kidney Disease and Blood Purification, Changsha, Hunan

Xiao Fu
Department of Nephrology, Second Xiangya Hospital, Central South University , Hunan Key Laboratory of Kidney Disease and Blood Purification, Changsha, Hunan

Lei Zhang
Department of Nephrology, Second Xiangya Hospital, Central South University , Hunan Key Laboratory of Kidney Disease and Blood Purification, Changsha, Hunan

Hong Liu
Department of Nephrology, Second Xiangya Hospital, Central South University , Hunan Key Laboratory of Kidney Disease and Blood Purification, Changsha, Hunan

Lin Sun
Department of Nephrology, Second Xiangya Hospital, Central South University , Hunan Key Laboratory of Kidney Disease and Blood Purification, Changsha, Hunan

Yinghong Liu (liuyingh2002@csu.edu.cn)
Department of Nephrology, Second Xiangya Hospital, Central South University , Hunan Key Laboratory of Kidney Disease and Blood Purification, Changsha, Hunan

---

Research Article

Keywords: Elderly patient, peritoneal dialysis, peritonitis, microbiology, outcome

Posted Date: April 8th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-385217/v1

Abstract

The microbiology and outcomes of peritoneal dialysis (PD) related peritonitis in elderly patients have not been thoroughly investigated. We aimed to investigate the microbiological distribution and clinical outcome in elderly patients with PD-associated peritonitis to guide clinical practice. We conducted a prospective, one center cohort study in Hunan province, China from September 1, 2014 to December 31, 2020. Among incident patients (n =279), basic clinical characteristics, pathogen distribution and prognosis of elderly PD patients (up to 65 years, n = 64) were compared with those of PD patients aged under 65 years (n = 215). The survival rate and technical survival rate were analyzed by Kaplan-Meier method. Among the 279 patients there were 394 peritonitis episodes, including 88 in elderly group, and 306 in younger groups. G+ bacteria were the main pathogenic bacteria in both groups (43.2% and 38.0%, respectively). Staphylococcus was the most common G+ bacteria. Peritonitis caused by fungal infection was significantly higher in elderly patients (P = 0.01), however, there is no significant difference in the proportions of G + bacteria and G- bacteria between the two groups. The most common G- bacteria was Escherichia coli. Interestingly, we found that Acinetobacter baumannii, polymicrobial infection and culture negative peritonitis in the elderly patients was significantly higher than that in other patients. Additionally, elderly PD patients had higher peritonitis-related mortality (HR=7.27, P = 0.01). However, the technical survival rate was similar (P = 0.67) in both elderly and other patients. Taken together, this retrospective cohort study found that elderly patients had a higher probability of peritonitis caused by of Acinetobacter baumannii, fungi and polymicrobial infections. In addition, the elderly peritonitis patients had a higher risk of mortality. Understanding the characteristics of microbiology and clinical outcome in elderly patients will help us to take effective measures to reduce the incidence of elderly PD-associated peritonitis.

Background

Chronic kidney disease (CKD) is a serious public health problem, and its incidence is increasing year by year. With the aging of the world's population, the number of elderly patients with end-stage renal disease (ESRD) is increasing. Peritoneal dialysis (PD) is an important kidney replacement therapy. PD has been reported to protect residual renal functions better and other advantages in many studies[1]. Therefore, more and more ESRD patients, especially elderly patients choose to receive PD treatment[2]. However, peritonitis is still a common and serious complication of PD. PD-associated peritonitis is the major cause of death in 15% of patients on PD[3, 4]. Moreover, a single episode of severe peritonitis or multiple peritonitis episodes usually leads to peritoneal ultrafiltration failure and is the most common cause of switching to hemodialysis [5]. Whether elderly patients on PD have an increased risk of peritonitis? Here, we did a retrospective cohort study based on data from the Second Xiangya Hospital of Central South University. We analyzed 394 incident patients on PD between September 1, 2014 and December 31, 2020. Patients were separated into two age groups: up to 65 and over of 65 years old, in order to understand the characteristics of PD-related peritonitis in the elderly, and provide guidance for clinical prevention and treatment.

Materials And Methods

Study population

394 peritonitis episodes from the Second Xiangya Hospital of Central South University between September 1, 2014 and December 31, 2020 were included. We excluded patients who were under 18 years old and patients with no regular follow-up and incomplete data. Patients were divided into two groups: the elderly group (≥65 years old) and the young and middle-aged group (< 65 years old). Approval of study by research ethics committee of Central South University and informed consents were provided prior to their inclusion in the study.

The diagnosis of peritonitis

The diagnosis of PD-associated peritonitis follows the 2016 Guidelines of the International Peritoneal Dialysis Association: (1) clinical features consistent with peritonitis, i.e., abdominal pain or cloudy dialysis effluent; (2) dialysis effluent white cell count > 0.1×10^9 /L (after a dwell time of at least 2 hours), with .50% neutrophils; and (3) positive dialysis effluent culture . The diagnosis of PD-associated peritonitis requires any two of the following features[6].

Relevant definitions

Peritonitis related death was defined as death of the patient due to peritonitis or death within 4 weeks from the onset of peritonitis. Cure: Peritonitis is completely relieved after treatment, and there is no need to continue anti-infection. Extubation: Because of peritonitis, the peritoneal dialysis cannot be continued and the peritoneal dialysis tube is permanently removed and transferred to hemodialysis. Multiple organism infection: refers to two or more pathogenic microorganisms in the peritoneal dialytic effluent.

Statistical analysis

SPSS25.0 software was used for statistical analysis, mean ± standard deviation or median and range, as appropriate. Student's t-test was used for comparison between normal distribution data sets, and Wilcoxon rank-sum test was used for comparison between non-normal distribution data sets. Statistical data were presented by composition ratio or rate, Chi-square test or Fisher exact test were used for comparison, and Kaplan-Meier method was used to calculate cumulative survival rate and draw survival curve, and Log-rank method was used to test differences between groups. Hazard ratios (HRs) and 95% confidence intervals (CIs) for the incidence of PD-associated peritonitis were assessed using Cox regression analysis and interaction analysis with the confounding factors of sex, age and primary disease. Values of $P < 0.05$ was considered statistically significant.

Results

Patients characteristics

Of the 279 patients included in the study, 64 were older than 65 years. The median ages at dialysis initiation were respectively 72 and 48 years for the elderly group and the other patients. Detailed information about patient characteristics is provided in Table 1. Among the 279 patients there were 394 peritonitis episodes, including 88 in the elderly group, and 306 in other groups. Until the occurrence of peritonitis, the average dialysis age of the elderly group was 36.98 ± 3.51 months, and the other patients were 30.29 ± 1.60 months. Chronic glomerulonephritis was the main primary disease in PD-peritonitis patients, followed by hypertension and diabetic nephropathy. Table 1 shows the different demographic and baseline clinical parameter between the two groups across age, that elderly patients had lower lower serum albumin, serum creatinine, uric acid, and serum phosphorus than the younger PD patients (Table 1).

Table 1
Baseline characteristic of the study population

	Elderly group(n = 64, 88 episodes)	Younger group(n = 215, 306 episodes)	χ2/F	P
Gender(male)	57	170	2.493	0.114
Age(year)	71.6 ± 4.86	47 ± 10.362	45.69	0.000*
Dialysis age(month)	36.98 ± 3.51	30.29 ± 1.60	1.418	0.28
BMI(kg/m2)	22.51 ± 3.13	21.89 ± 3.13	0.178	0.324
Primary disease				
Chronic glomerulonephritis	33(37.5%)	194(63.4%)	25.738	0.000*
Diabetic nephropathy	15(17%)	24(7.8%)	6.489	0.011*
Hypertensive nephropathy	25(28.4%)	55(18%)	4.599	0.032*
Obstructive nephropathy	12(13.6%)	3(1%)	29.892	0.000*
other	3(3.2%)	25(8.4%)		
Laboratory findings, mean ± SD				
Hemoglobin, g/L	98.52 ± 22.81	100.38 ± 20.13	0.727	0.652
Albumin, g/L	33.11 ± 3.97	34.99 ± 5.36	4.599	0.032*
BUN, mmol/L	18.36 ± 6.65	20.79 ± 7.11	0.506	0.08
Creatinine, mmol/L	680.2 ± 308.2	889.5 ± 312.0	0.823	0.001*
Uric acid, mmol/L	387.5 ± 53.6	445.2 ± 99.4	7.424	0.000*
TCHO, mmol/L	4.91 ± 1.21	4.87 ± 1.20	0.013	0.875
LDL, mmol/L	3.08 ± 1.02	3.02 ± 0.89	0.601	0.744
Calcium, mmol/L	2.05 ± 0.23	2.07 ± 0.23	0.023	0.617
Phosphorus, mmol/L	1.47 ± 0.49	1.71 ± 0.48	0.208	0.012*
GFR (mL/min/1.73 m2)	3.57 ± 2.68	3.41 ± 2.57	0.438	0.756

BMI: body mass index; TCHO: Total cholesterol; LDL: low density lipoprotein; PTH: parathyroid hormone; GFR: glomerular filtration rate; nPCR: normalized catabolic rate

	Elderly group(n = 64, 88 episodes)	Younger group(n = 215, 306 episodes)	χ2/F	P
iPTH, mmol/L	23.75 ± 16.28	32.26 ± 24.31	3.705	0.025*
Total Kt/V	1.81 ± 0.64	2.10 ± 0.93	0.709	0.111
nPCR (g/kg/day)	1.28 ± 0.31	1.58 ± 0.50	1.671	0.119
BMI: body mass index; TCHO: Total cholesterol; LDL: low density lipoprotein; PTH: parathyroid hormone; GFR: glomerular filtration rate; nPCR: normalized catabolic rate				

Microbiology distribution characteristics

79 strains of pathogenic bacteria were cultured in the elderly group, among which 38 PD-peritonitis episodes were G + bacteria (43.2%), 26 episodes were G- bacteria (29.5%), and 12 episodes were fungi (13.6%). 202 strains of pathogenic bacteria were cultured in other peritonitis patients, among which 116 episodes of PD-peritonitis were G + bacteria, accounting for 38.0%; 69 episodes were G- bacteria, accounting for 22.6%; 17 episodes were fungi, accounting for 5.6%. G + bacteria were the main pathogenic bacteria in both elderly group and other patients (43.2% and 38.0%, respectively). Peritonitis caused by fungal infection was significantly higher in the elderly group than other patients (X2 = 6.55, P = 0.01), but there is no significant difference in the proportions of G + bacteria and G- bacteria between the two groups (P = 0.38, 0.18).

We further analyzed G + bacteria, and the results showed that staphylococcus was the most common G + organism in both groups, the proportions of staphylococcus, streptococcus and enterococcus in the two groups were not statistically significant (P = 0.12,0.71, 0.50). The most common G- bacteria was Escherichia coli, but the difference between the two groups was not statistically significant (χ 2 = 0.08, P = 0.77), while the proportion of Acinetobacter baumannii in the elderly group was significantly higher than that in other patients (χ 2 = 9.25, P = 0.002), as shown in Table 2.

Table 2
Pathogenic microorganism distribution and composition ratio of PD related peritonitis in elderly and younger patients

	Elderly group n = 88		Younger group n = 306			
	Episodes	Ratio(%)	Episodes	Ratio(%)	χ2	P
Total peritonitis episodes	88	71.54%	306	39.23%		
G + bacteria	38	43.20%	116	38.00%	0.76	0.383
Staphylococcus	27	30.70%	69	22.50%	2.453	0.117
Coagulase-negative staphylococcus	12	13.60%	34	11.10%	0.423	0.516
Staphylococcus epidermidis	3	3.40%	17	5.60%	0.654	0.419
Staphylococcus hemolyticus	2	2.30%	3	1.10%	0.911	0.34
Staphylococcus aureus	10	11%	30	9.80%	0.182	0.669
Streptococcus	8	9.10%	32	10.50%	0.14	0.708
Hemolytic streptococcus	3	3.40%	19	6.20%	1.016	0.313
Streptococcus salivarius	1	1.10%	8	2.60%	0.669	0.413
Enterococcus	1	1.10%	7	2.30%	0.455	0.5
G- bacteria	26	29.50%	69	22.60%	1.786	0.181
Escherichia coli	8	9.10%	31	10.10%	0.083	0.773
Acinetobacter baumannii	7	8.00%	5	1.60%	9.246	0.002*
Klebsiella pneumoniae	4	4.50%	9	2.90%	0.551	0.458
Pseudomonas aeruginosa	2	2.30%	6	2.00%	0.033	0.855
Neisseria	0	0.00%	4	1.30%	1.162	0.281
Fungus	12	13.60%	17	5.60%	6.545	0.011*
Candida albicans	6	6.80%	6	2.00%	5.461	0.019*
Saccharomycetes	1	1.14%	2	2.30%		
Multiorganism	7	8.00%	7	2.30%	6.405	0.011*
Culture negative	20	22.70%	107	35.00%	4.688	0.03*

Classification of pathogenic bacteria and the outcome of treatment of peritonitis

According to the results of pathogen culture, peritonitis episodes were divided into single G + bacteria, single G-bacteria, single fungi, mixed pathogenic infection and culture negative peritonitis. The proportion of single gram-positive bacteria and gram-negative bacteria in the two groups was similar. The infection rate of single fungus in the elderly group was higher than that of other patients, but the difference was not statistically significant(P = 0.14). The incidence of polymicrobial infection infection and culture negative peritonitis in the elderly group was significantly higher than that in other patients (χ 2 = 6.41, P = 0.01; χ 2 = 4.69, P = 0.03), as shown in Table 3. In terms of treatment outcome, the cure rates of the two groups were 72.70% and 80.10%, the extubation rates were 19.30% and 17.30%, and the mortality rates were 6.80% and 0.70%, respectively. The cure rate of peritonitis in elderly group was lower than that in other patients ,but the difference was not statistically significant (χ 2 = 2.18, P = 0.14), while the mortality of peritonitis in the elderly group was significantly higher than that in other patients(χ 2 = 12.521, P = 0.000402). There was no significant difference in extubation rate between the two groups, as shown in Table 4.

Table 3
The composition ratio of peritonitis caused by different types of pathogenic microorganism in elderly and younger patients

	Elderly group n = 88		Younger group n = 306			
	Episodes	Incidence rate %	Episodes	Incidence rate %	χ2	P
Single G + bacteria	33	37.50%	113	37.00%	0.006	0.939
Single G- bacteria	21	24%	64	21.00%	0.334	0.563
Single fungus	8	9.10%	15	4.90%	2.182	0.14
Multiorganism infections	7	8.00%	7	2.30%	6.405	0.011*
Culture negative	20	22.70%	107	35.00%	4.688	0.03*

Table 4
Clinical outcomes of peritoneal dialysis-associated peritonitis in elderly and younger patients

Outcome	Episodes	Incidence rate %	Episodes	Incidence rate %	χ2	P
Cure	64	72.70%	245	80.10%	2.175	0.14
Extubation	17	19.30%	53	17.30%	0.187	0.666
Death[a]	6	6.80%	2	0.70%	13.057	0.000*
Others[b]	1	1.10%	7	2.30%	0.455	0.50

a: Peritonitis related deaths; b: Patients who have not been completely cured but have been lost to follow-up due to various reasons.

Survival time and technical survival time of peritonitis patients

Taking all-cause death of the patients as the end point, the survival time of the two groups were analyzed. Figure 1 showed the 1-year, 3-year, and 5-year survival rates of the elderly group were 92%, 89%, and 82%, respectively, while younger patients were 99%, 98%, and 94% respectively. We also performed COX regression analysis on survival time, further confirming that age is an independent factor that affects the survival outcome of patients with peritoneal dialysis-related peritonitis (p = 0.02). Compared with other patients, the risk of death after peritonitis in the elderly group is significantly higher, HR = 7.27 (95%CI: 1.45–36.45). With "removal of the peritoneal dialysis tube" as the end point, the technical survival rate of the two groups of patients was analyzed, and there was no significant difference between the two groups of patients (P = 0.67), as shown in Fig. 2.

Discussion

The present single-center retrospective cohort study investigated the microbiology and clinical outcomes of elderly PD patients, as compared with younger PD.The results showed that the infection rate of Acinetobacter baumannii in elderly PD patients was higher as compared to younger PD patients. And elderly patients were more prone to fungal infection or polymicrobial infection. In addition, the survival rate of elderly PD patients was inferior to those of younger patients. However, the technical survival rate was similar between the elderly and younger PD groups.

Peritonitis is a major complication of PD, and often resulting in the termination of peritoneal dialysis[7]. In this study, the main pathogenic microorganism of peritonitis in both elderly and younger patients were G + bacteria, accounting for 42.7% and 38.5% respectively. Staphylococcus predominated for PD-related peritonitis in both groups. This bacterial flora distribution and high incidence of Staphylococcus were similar to previous reports[8–11]. And such results of the predominance of gram-positive bacteria were similar to the studies in America, Canada, Scotland, and Hong Kong[12–15]. The type of pathogenic microorganism usually indicates a possible cause of infection. Coagulase-negative staphylococcal

peritonitis, especially those caused by Staphylococcus epidermidis, is mainly caused by contact contamination. Staphylococcus aureus infection is related to contact contamination or catheter infection. This suggests that PD patients should further strengthen aseptic operation concept, avoid contact infection.

G-bacteria are mostly related to intestinal infection and constipation[16]. In this study, the most common G- bacteria was Escherichia coli. The proportion of G- bacteria in the elderly group(28%) was higher than that in the younger group (22.2%), but the difference was not statistically significant. Nevertheless, we still need to take positive measures, including strengthening dietary guidance for elderly PD patients, paying attention to regulating intestinal flora, avoiding hypokalemia, improving constipation, and timely treating intestinal infections, so as to reduce the risk of G- bacteria infections in PD patients. Interestingly, we found that the proportion of Acinetobacter baumannii in elderly group was significantly higher than that in younger group. Several researchers proposed that Acinetobacter peritonitis often occurred with an immunocompromised status[17, 18]. Since elderly patients often have weakened immune systems, this explains why they are more susceptible to Acinetobacter infection. Acinetobacter baumannii infections are reportedly associated with 10–20% higher attributable mortality and longer length of hospital stay[19, 20],owing to their high antibiotic resistance rates[21]. This also explains the higher mortality rate among older patients in the study. Therefore, clinicians should pay more attention to the nutrition of elderly patients.

Compared with bacterial peritonitis, fungal peritonitis is rare in PD related peritonitis. representing only 1–12% of overall peritonitis in PD patients [22, 23], yet bringing terrible damage by higher rates of catheter loss, longer hospital stay, permanent transfer to HD, and mortality[6, 24]. For most fungal peritonitis cases, Candida species are the commonest pathogen, accountable for 70–90% of fungal peritonitis in adults[22, 24], where Candida albicans has been classically considered predominant. Our findings were similar to those of these studies, and fungal infections were higher in elderly patients. Previous studies have shown that malnutrition, diabetes mellitus, prior use of antibiotics, immunosuppressed state, and prolonged time on PD are the main risk factors for fungal peritonitis[23, 25]. The elderly often suffer from malnutrition, poor immune function and diabetes mellitus and so on. Therefore, the nutrition management of the elderly peritoneal dialysis patients should be strengthened and the complications should be treated actively.

The incidences of culture-negative peritonitis were 22.7% (20/88) in elderly patients, 35.0% (107/306) in younger patients. The relatively high culture-negative proportion in both groups may be primarily related to the early use of antibiotics prior to admission to our center. In addition, a small part of the reasons may be limited effluent culture technique, although the microbial culture technical in our hospital has been greatly improved in recent years. Therefore, we should follow the recommendations of the ISPD guidelines ,such as centrifugation of PD effluent, incubation in aerobic, microaerophilic and anaerobic environments, using antibiotic neutralisation bottle to further improve the positive rate of effluent microbial culture[6, 26].

In terms of the clinical outcome of this study, the results showed that the death rates of elderly PD patients was higher than that of younger patients, this may have to do with elderly patients having more comorbidity, poorer performance, and were more frequently malnourished. However, the decannulation rate has no statistical significance between the two groups. Furthermore, the survival analysis of the two groups was carried out in this study, and the results showed that the overall survival rate of the elderly group was worse than that of the younger group; but the technical survival rate was similar between elderly and younger PD patients. Regardless of age, peritonitis was the leading cause of technical failure in PD patients. The incidence of peritonitis of elderly PD patients was higher than that of younger PD patients.

De Vecchi et al.[27] also reported that patient survival rate was poorer and the incidence of peritonitis was higher in the elderly PD patients than younger PD patients, whereas the technical survival was similar between the two groups. Lim WH et al.[28] reported that the hazard ratios for technical failure were similar across the age groups despite higher risk of peritonitis-related mortality. Hyunsuk K et al. [29] likewise reported inferior patient survival in elderly PD than in younger PD patients, but similar technical survival; and additional studies similarly showed no differences in the technical survival rates between elderly and younger PD patients [30–32].

The main limitation of our study was single-center, retrospective and relatively small sample size of elderly PD patients. Moreover, the risk factors of peritoneal dialysis-related peritonitis in elderly patients were not further analyzed in this study. Therefore, a multi-center, large sample size, long-term, prospective study is needed in the future to confirm our findings.

To sum up, this retrospective cohort study found that elderly patients had a higher probability of peritonitis caused by of baumannii, fungi and multiple microorganisms mixed infections. In addition, the elderly peritonitis patients had a higher risk of death. Understanding the characteristics of microbiology and clinical outcome in elderly patients will help to take effective measures to reduce the incidence of PD-associated peritonitis.

Declarations

Acknowledgements

We appreciate all the participants and their families.We also thank the members of the study team from Department of Nephrology of Second Xiangya Hospital Affiliated to Central South University for their assistance in completing this project. This work was supported by grants from by National Natural Science Foundation of China (81800649), Natural Science Foundation of Hunan Province(2018JJ3727) and Changsha Municipal Natural Science Foundation(kq2014235).

Author contributions

P.S. collected clinical data, drafted and revised manuscript, J.L.,S.Y.collected clinical data and searched the relative literatures, N.Z. searched the relative literatures, made analysis and revised the English of manuscript. X.F., L.Z., H.L.and L.S. provided with clinical assistance and contributed for the acquisition of these data. Y.L. revised the manuscript and takes responsibility for the work, all authors have read and approve of the final version.

Competing interests

The authors declare no competing interests.

References

1. Tokgoz, B. Clinical advantages of peritoneal dialysis. *Perit Dial Int.* **29 Suppl 2**:S59-61(2009).
2. Li, P.K. *et al*. Changes in the worldwide epidemiology of peritoneal dialysis. *Nat Rev Nephrol.* **13**:90-103(2017).
3. Szeto, C.C., Wong, T.Y., Chow, K.M., Leung, C.B., Li, P.K. Are peritoneal dialysis patients with and without residual renal function equivalent for survival study? Insight from a retrospective review of the cause of death. *Nephrol Dial Transplant.* **18**:977-982(2003).
4. Boudville, N. *et al*. Recent peritonitis associates with mortality among patients treated with peritoneal dialysis. *J Am Soc Nephrol.* **23**:1398-1405(2012).
5. Htay, H. *et al*. Multicenter Registry Analysis of Center Characteristics Associated with Technique Failure in Patients on Incident Peritoneal Dialysis. *Clin J Am Soc Nephrol.* **12**:1090-1099(2017).
6. Li, P.K. *et al*. ISPD Peritonitis Recommendations: 2016 Update on Prevention and Treatment. *Perit Dial Int.* **36**:481-508(2016).
7. Song, P., Deng, J., Hou, T., Fu, X., Zhang, L., Sun, L., Liu, Y. Aeromonas sobria peritonitis in a peritoneal dialysis (PD) patient: a case report and review of the literature. *BMC Nephrol.* **20**:180(2019).
8. Hsieh, Y.P., Wang, S.C., Chang, C.C., Wen, Y.K., Chiu, P.F., Yang, Y. The negative impact of early peritonitis on continuous ambulatory peritoneal dialysis patients. *Perit Dial Int.* **34**:627-635(2014).
9. Barretti, P., Doles, J.V., Pinotti, D.G., El Dib, R. Efficacy of antibiotic therapy for peritoneal dialysis-associated peritonitis: a proportional meta-analysis. *BMC Infect Dis.* **14**:445(2014).
10. Govindarajulu, S., Hawley, C.M., McDonald, S.P., Brown, F.G., Rosman, J.B., Wiggins, K.J., Bannister, K.M., Johnson, D.W. Staphylococcus aureus peritonitis in Australian peritoneal dialysis patients: predictors, treatment, and outcomes in 503 cases. *Perit Dial Int.* **30**:311-319(2010).
11. Ma, X. *et al*. Analysis of risk factors and outcome in peritoneal dialysis patients with early-onset peritonitis: a multicentre, retrospective cohort study. *BMJ Open.* **10**:e029949(2020).
12. Troidle, L., Gorban-Brennan, N., Kliger, A., Finkelstein, F. Differing outcomes of gram-positive and gram-negative peritonitis. *Am J Kidney Dis.* **32**:623-628(1998).
13. Zelenitsky, S.A., Howarth, J., Lagacé-Wiens, P., Sathianathan, C., Ariano, R., Davis, C., Verrelli, M. Microbiological Trends and Antimicrobial Resistance in Peritoneal Dialysis-Related Peritonitis, 2005

to 2014. *Perit Dial Int.* **37**:170-176(2017).

14. Brown, M.C., Simpson, K., Kerssens, J.J., Mactier, R.A. Peritoneal dialysis-associated peritonitis rates and outcomes in a national cohort are not improving in the post-millennium (2000-2007). *Perit Dial Int.* **31**:639-650(2011).
15. Ma, T.K., Chow, K.M., Kwan, B.C., Pang, W.F., Leung, C.B., Li, P.K., Szeto, C.C. Peritonitis before Peritoneal Dialysis Training: Analysis of Causative Organisms, Clinical Outcomes, Risk Factors, and Long-Term Consequences. *Clin J Am Soc Nephrol.* **11**:1219-1226(2016).
16. Szeto, C.C., Chow, K.M. Gram-negative peritonitis--the Achilles heel of peritoneal dialysis? *Perit Dial Int.* **27 Suppl 2**:S267-271(2007).
17. Galvao, C., Swartz, R., Rocher, L., Reynolds, J., Starmann, B., Wilson, D. Acinetobacter peritonitis during chronic peritoneal dialysis. *Am J Kidney Dis.* **14**:101-104(1989).
18. Lye, W.C., Lee, E.J., Leong, S.O., Kumarasinghe, G. Clinical characteristics and outcome of Acinetobacter infections in CAPD patients. *Perit Dial Int.* **14**:174-177(1994).
19. Baboolal, K., McEwan, P., Sondhi, S., Spiewanowski, P., Wechowski, J., Wilson, K. The cost of renal dialysis in a UK setting--a multicentre study. *Nephrol Dial Transplant.* **23**:1982-1989(2008).
20. Falagas, M.E., Bliziotis, I.A., Siempos, II. Attributable mortality of Acinetobacter baumannii infections in critically ill patients: a systematic review of matched cohort and case-control studies. *Crit Care.* **10**:R48(2006).
21. Abbo, A., Carmeli, Y., Navon-Venezia, S., Siegman-Igra, Y., Schwaber, M.J. Impact of multi-drug-resistant Acinetobacter baumannii on clinical outcomes. *Eur J Clin Microbiol Infect Dis.* **26**:793-800(2007).
22. Nadeau-Fredette, A.C., Bargman, J.M. Characteristics and outcomes of fungal peritonitis in a modern North American cohort. *Perit Dial Int.* **35**:78-84(2015).
23. Hu, S., Tong, R., Bo, Y., Ming, P., Yang, H. Fungal peritonitis in peritoneal dialysis: 5-year review from a North China center. **47**:35-43(2019).
24. Giacobino, J., Montelli, A.C., Barretti, P., Bruder-Nascimento, A., Caramori, J.T., Barbosa, L., Bagagli, E. Fungal peritonitis in patients undergoing peritoneal dialysis (PD) in Brazil: molecular identification, biofilm production and antifungal susceptibility of the agents. *Med Mycol.* **54**:725-732(2016).
25. Matuszkiewicz-Rowinska, J. Update on fungal peritonitis and its treatment. *Perit Dial Int.* **29 Suppl 2**:S161-165(2009).
26. Szeto, C.C. *et al*. ISPD Catheter-Related Infection Recommendations: 2017 Update. *Perit Dial Int.* **37**:141-154(2017).
27. De Vecchi, A.F., Maccario, M., Braga, M., Scalamogna, A., Castelnovo, C., Ponticelli, C. Peritoneal dialysis in nondiabetic patients older than 70 years: comparison with patients aged 40 to 60 years. *Am J Kidney Dis.* **31**:479-490(1998).
28. Lim, W.H., Dogra, G.K., McDonald, S.P., Brown, F.G., Johnson, D.W. Compared with younger peritoneal dialysis patients, elderly patients have similar peritonitis-free survival and lower risk of technique

failure, but higher risk of peritonitis-related mortality. *Perit Dial Int.* **31**:663-671(2011).

29. Kim, H. *et al*. Elderly Peritoneal Dialysis Compared with Elderly Hemodialysis Patients and Younger Peritoneal Dialysis Patients: Competing Risk Analysis of a Korean Prospective Cohort Study. *PLoS One.* **10**:e0131393(2015).
30. Yang, X., Fang, W., Kothari, J., Khandelwal, M., Naimark, D., Jassal, S.V., Bargman, J.M., Oreopoulos, D.G. Clinical outcomes of elderly patients undergoing chronic peritoneal dialysis: experiences from one center and a review of the literature. *Int Urol Nephrol.* **39**:1295-1302(2007).
31. Harris, S.A., Lamping, D.L., Brown, E.A., Constantinovici, N. Clinical outcomes and quality of life in elderly patients on peritoneal dialysis versus hemodialysis. *Perit Dial Int.* **22**:463-470(2002).
32. Li, P.K., Law, M.C., Chow, K.M., Leung, C.B., Kwan, B.C., Chung, K.Y., Szeto, C.C. Good patient and technique survival in elderly patients on continuous ambulatory peritoneal dialysis. *Perit Dial Int.* **27 Suppl 2**:S196-201(2007).

Figures

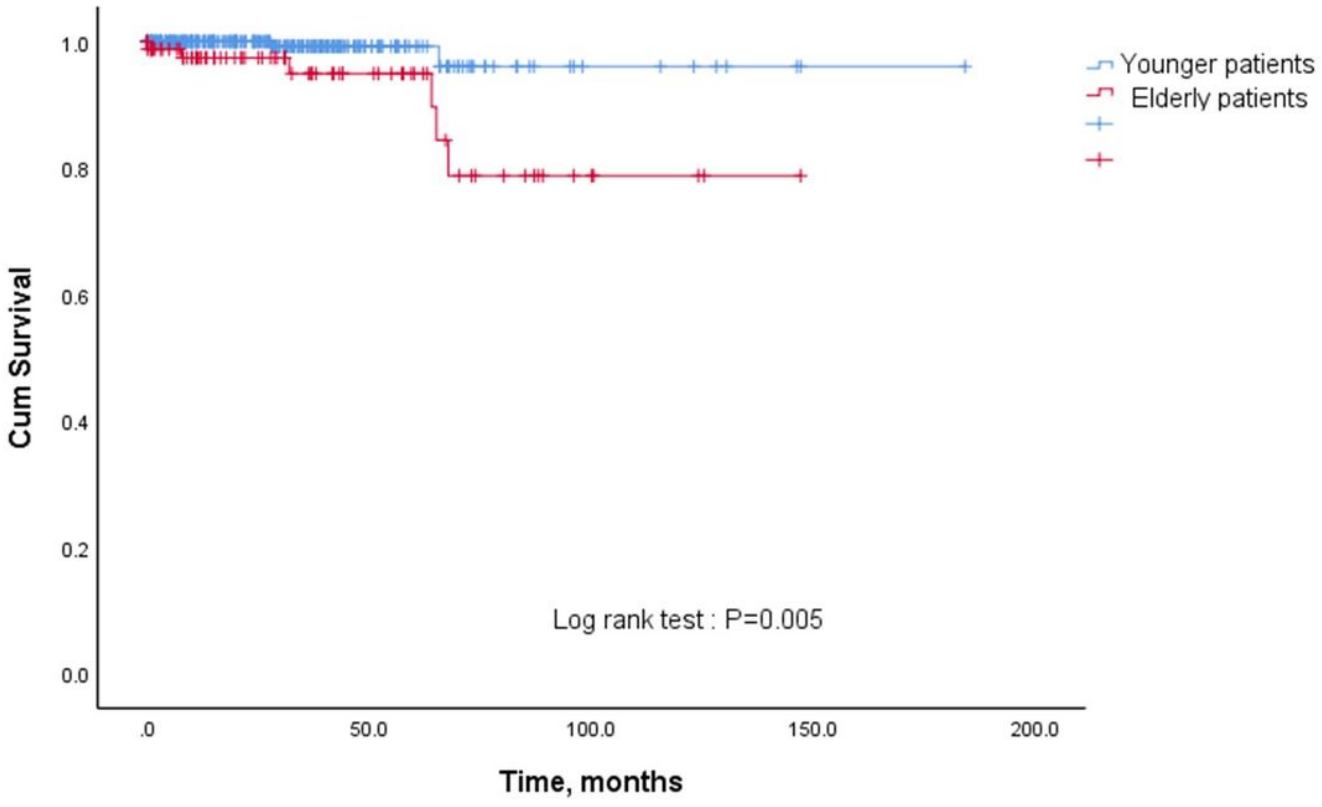

Figure 1

Patient survival according to elderly patients and younger patients with peritoneal dialysis-associated peritonitis. Log-rank test $\chi 2$ =7.867, p=0.005. And COX regression analysis further confirmed that age is

an independent factor that affects the survival outcome of patients with peritoneal dialysis-related peritonitis HR=7.27 (95%CI: 1.45-36.45), p=0.02.

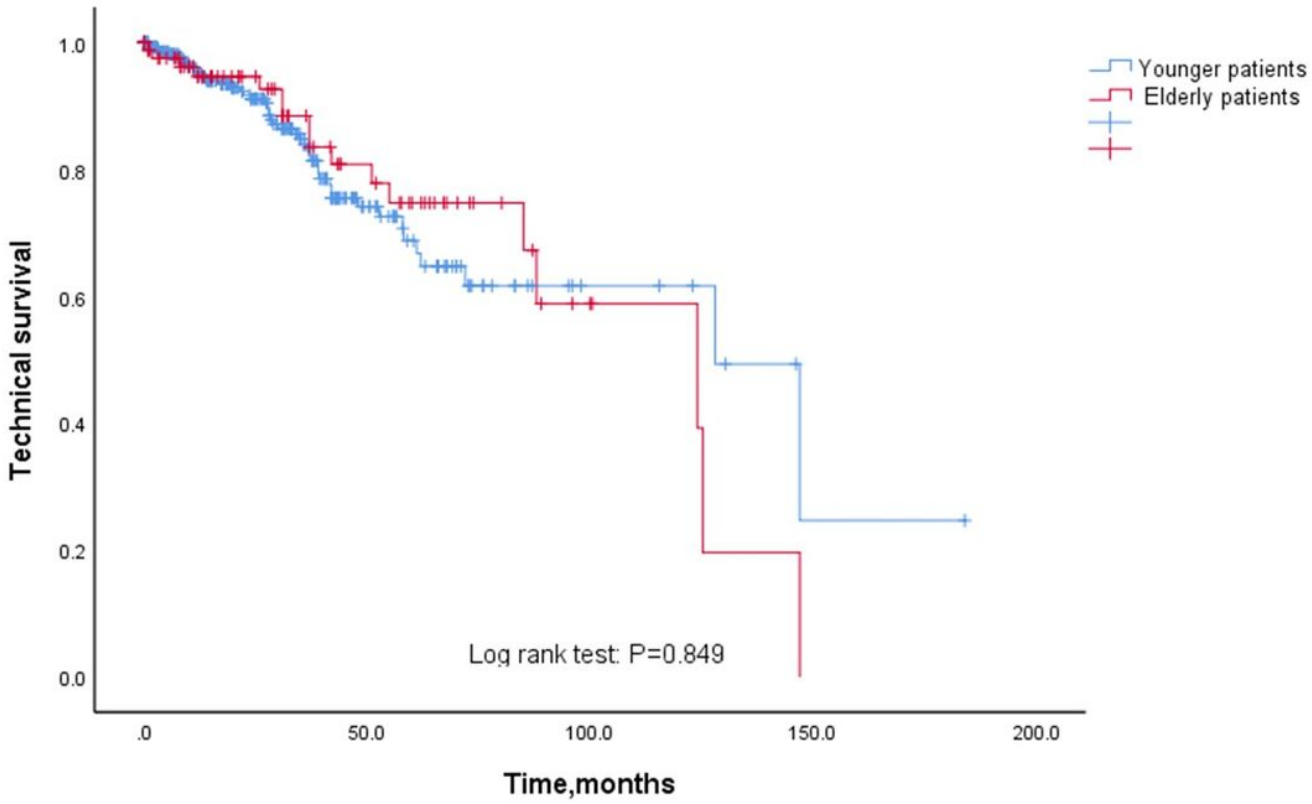

Figure 2

Technique survival according to elderly patients and younger patients with peritoneal dialysis-associated peritonitis. Log-rank test $\chi 2$ =0.036, p=0.849.