

# Evolving outcomes of peritoneal dialysis: secular trends at a single large center over three decades

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**Background:** Peritoneal dialysis (PD) is improving as a renal replacement therapy for end-stage renal disease (ESRD) patients. We analyzed the main outcomes of PD over the last three decades at a single large-scale PD center with an established high-quality care system.

**Methods:** As a retrospective cohort study, we included participants (n = 1,203) who began PD between 1990 and 2019. Major PD-related outcomes were compared among the three 10-year cohorts.

**Results:** The 1,203 participants were 58.3% male with a mean age of 47.9 ± 13.8 years. The median PD treatment duration was 45 months (interquartile range, 19–77 months); 362 patients (30.1%) transferred to hemodialysis, 289 (24.0%) received kidney transplants, and 224 (18.6%) died. Overall, the 5- and 8-year adjust patient survival rates were 64% and 49%, respectively. Common causes of death included infection (n = 55), cardiac (n = 38), and cerebrovascular (n = 17) events. The 5- and 8-year technique survival rates were 77% and 62%, respectively, with common causes of technique failure being infection (42.3%) and solute/water clearance problems (22.7%). The 5-year patient survival significantly improved over time (64% for the 1990–1999 cohort vs. 93% for the 2010–2019 cohort). The peritonitis rate also substantially decreased over time, from 0.278 episodes/patient-year (2000–2004) to 0.162 episodes/patient-year (2015–2019).

**Conclusion:** PD is an effective treatment option for ESRD patients. There was a substantial improvement in the patient survival and peritonitis rates over time. Establishing adequate infrastructure and an effective system for high-quality PD therapy may be warranted to improve PD outcomes.

**Keywords:** Peritoneal dialysis, Peritonitis, Survival, Technique failure

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## Introduction

The global incidence of end-stage renal disease (ESRD) is rapidly increasing, which poses a major burden on health-care systems around the world [1]. To date, no definitive randomized clinical trials have been conducted on peritoneal dialysis (PD) and in-center hemodialysis (HD) [2]. However, several observational studies have reported comparable or better survival [3–5] in patients with PD, particularly during the first 2 years after dialysis initiation. Additionally, PD has been associated with better preservation of residual renal function [6], improved cognition [7], a higher likelihood of retaining employment [8], and improved health-related quality of life (HRQOL) [9]. The Centers for Medicare and Medicaid Services in the United States has acknowledged these benefits of PD relative to HD and has also implemented the ESRD prospective payment system, which incentivizes PD treatment by bundling dialysis, medications, and other related services into a single payment [10].

However, despite its numerous clinical benefits, PD is still underutilized globally [11]. PD underuse may be attributable to the misconception that PD is inferior to HD [12] and also inadequate PD training of the nephrologists [13,14]. These factors lead patients to have less confidence in self-care and also in their ability to prepare for renal replacement therapy (RRT) initiation.

The major outcomes of PD (such as patient survival, technique survival, and peritonitis) vary widely depending on sociodemographics [15–17], race [18], center size [19,20], and center experience [21]. We conducted this retrospective cohort study to investigate the secular changes in major outcomes of incident PD patients over the last three decades at a single large PD center. We also explored recent advances in PD therapy and evaluated how our center's ongoing efforts to improve quality have translated into improved outcomes over time.

## Methods

### Study design and population

This was a single-center retrospective cohort study from the Seoul National University Hospital (SNUH) PD Center in Seoul, Korea. The SNUH PD Center launched its PD program in the late 1980s. It is currently one of the largest

PD centers in Korea and treats >1,300 cumulative and >300 prevalent PD patients. Clinical data from all incident PD patients since 1990 were collected. In 2000, the SNUH PD registry was established to prospectively collect patient information including age, sex, socioeconomic status, any previous RRT, comorbidities, biochemistry, peritoneal function test results, PD adequacy, PD-related infections, technique failure and its cause, and death.

The SNUH PD Center began a multidisciplinary predialysis education (MPE) program for chronic kidney disease (CKD) in 2002 to provide detailed information on diet, medication, and modality selection for advanced CKD patients who were expected to begin RRT within the next 6 months [22]. During the break-in period after PD catheter implantation, all patients and their caregivers were given intensive one-on-one education and training for PD exchange procedures, exit-site care, and self-management by professionally trained nurses [23]. After PD initiation, the participants were scheduled to visit the PD center regularly each 1 to 3 months for an evaluation and to receive prescriptions. They were also offered regular home visits for retraining at home [24], where most of the PD fluid exchanges and self-care procedures are carried out. To minimize inter-individual variation between the treating nephrologists and to facilitate communication within the PD team, we established a standard operating procedure for PD treatment and care. Regular monitoring and continuous quality improvement have been conducted across diverse areas, such as PD-related infections, dialysis adequacy, blood pressure control, fluid overload, technique failure, and mortality.

For this study, we included incident PD patients 18 years or older who began PD as their first RRT between 1990 and 2019. The participants who were transferred from other PD centers or transferred to PD treatment from other RRT modalities were excluded. Patients who underwent PD for less than 3 months were also excluded. Comorbidities were evaluated using the Davies comorbidity score, including ischemic heart disease, peripheral vascular disease, left ventricular dysfunction, malignancy, diabetes mellitus (DM), systemic collagen vascular disease, and others. The comorbidity score was categorized into three risk groups: low, a score of 0; medium, a score from 1 to 2; and high, a score of  $\geq 3$  [25]. Cardiovascular disease was defined as a composite event of ischemic heart disease, peripheral vascular disease, left ventricular dysfunction, and cerebral

vascular abnormality.

The study was approved by the Ethical Committee of Seoul National University Hospital (NO. H-2004-222-1119), and informed consent was waived because of the retrospective study design. Personal information was de-identified prior to our analyses. All clinical research processes were conducted in accordance with the guidelines of the 2008 Declaration of Helsinki.

### Outcome measures

All patients were categorized into three cohorts based on the year in which they began receiving PD; 1990–1999, 2000–2009, or 2010–2019, with the 1990–1999 cohort being the reference group. The participants were followed until the time of their death, their transfer to another RRT, their transfer to another hospital, or until December 31, 2019, whichever occurred first. The primary outcome among all cohort groups was the all-cause mortality, which was analyzed using an as-treated approach. For patient survival, the patients were censored at the time of loss to follow-up or 90 days after they switched to HD or received a kidney transplant. Deaths within 90 days after a modality switch were also considered to be PD-related. Specific causes of death were compared among the three cohort groups. For cause-specific death analysis, deaths related to other causes were censored for analysis.

Secondary outcomes were technique failure and peritonitis incidence. A PD technique failure was defined as a transfer to HD for >3 months for any reason, including infection, catheter-related problems, solute/water clearance problems, peritoneal leaks or hernias, psychosocial or medical issues, the risk of encapsulating peritoneal sclerosis (EPS), a diagnosis of EPS, and others. Deaths related to peritonitis, solute/water clearance problems, and an EPS risk or diagnosis were also regarded as technique failures. However, temporary HD (<90 days) was not regarded as a technique failure. Defining specific causes of technique failure followed a standardized classification recently suggested by the Peritoneal Dialysis Outcomes and Practice Patterns Study (PDOPPS) [26]. For technique failure, the participants were censored at the time of kidney transplantation, unrelated death, transfer to another center, or at the end of the observation period (December 31, 2019). Any diagnosis of PD-related peritonitis followed the International Society for Peritonitis Dialysis

(ISPD) guidelines [27]. Incidences of peritonitis associated with a specific causative microorganism were also evaluated. Detailed information on peritonitis was available from 2000 onwards in our registry dataset.

### Statistical analyses

Categorical variables were presented as frequencies and percentages, and these values were compared using a chi-square test. Age was categorized into three groups (18–40, 41–60, and >60 years). The crude survival and adjusted survival rates were estimated with a Cox proportional hazard model, and then adjustments were made with independent variables that were significant in the univariate analyses or with clinically relevant variables. For cause-specific mortality estimates, unrelated deaths were censored. We analyzed the trends of the peritonitis incidence and cause-specific peritonitis cases during each 5-year period as follows: 2000–2004, 2005–2009, 2010–2014, and 2015–2019. The peritonitis incidences were presented as episodes per patient-year at risk. SAS version 9.4 (SAS Institute, Cary, NC, USA) and IBM SPSS version 25.0 (IBM Corp., Armonk, NY, USA) were used for the statistical analyses. R version 3.6.3. (R Foundation for Statistical Computing, Vienna, Austria) was used for drawing plots. The p-values of <0.05 were considered statistically significant.

## Results

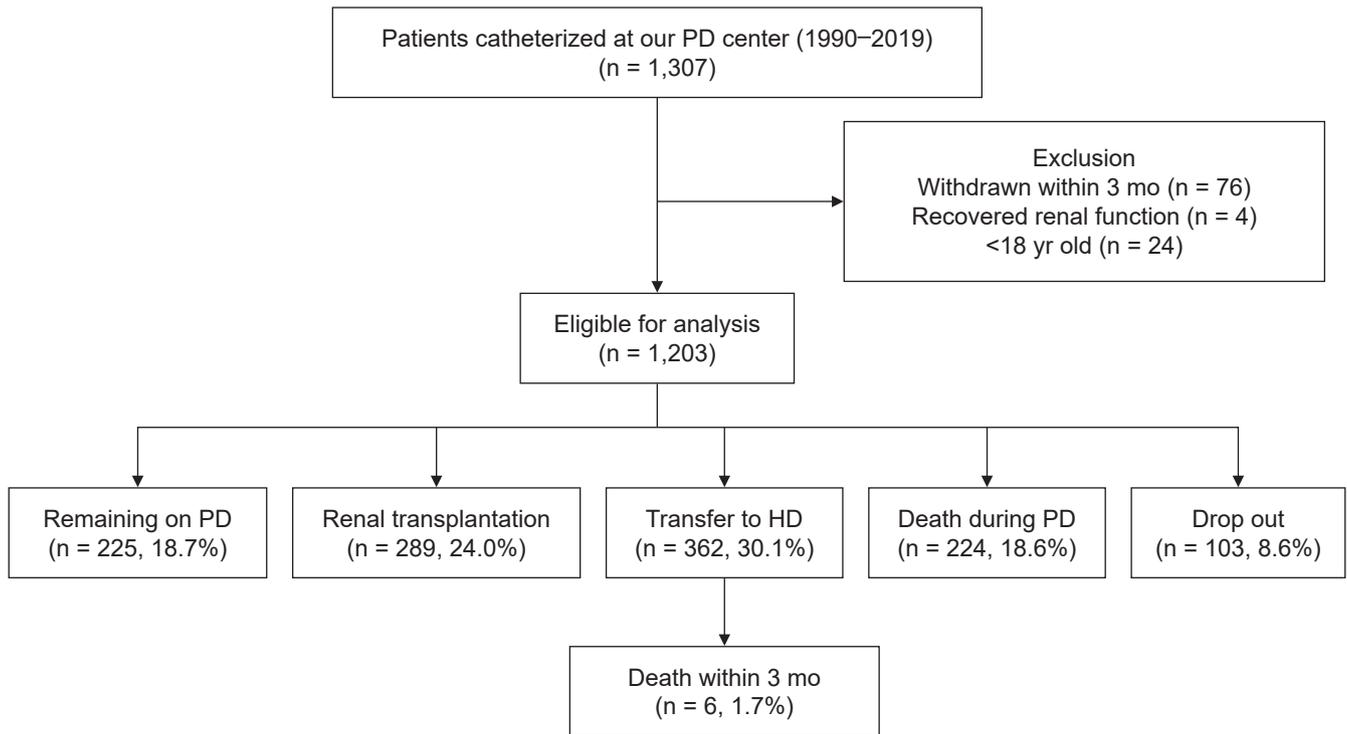
### Trends in the number of incident peritoneal dialysis patients

Since the MPE program was introduced at Seoul National University Hospital in 2002, the number of patients who have chosen PD as their initial RRT has increased at our PD center ([Supplementary Fig. 1](#), available online). Among all participants who began PD at our center from 1990 to 2019 (n = 1,307), we excluded the following patients; those who withdrew within 3 months (n = 76), recovered their renal function (n = 4), or were <18 years old (n = 24) ([Fig. 1](#)). Finally, we analyzed 1,203 participants. Of these, 289 underwent transplantation, 362 converted to HD, 224 died during PD, and 225 remained on PD. Six patients who switched to HD died within 3 months after they transferred to HD.

### The demographics and baseline characteristics of the three incident cohorts

Table 1 shows the baseline characteristics of each cohort. The overall mean age was  $47.9 \pm 13.8$  years (58.3% male and 28.9% with DM). The median duration of PD treatment was

45 months (interquartile range, 19–77 months). Participants aged from 41 to 60 years accounted for 46.6% of the total study population. The number of participants who started PD between the ages of 18 and 40 years increased over time. According to the Davies comorbidity scores, 38.7% and 5.9% were at medium and high risk, respectively.



**Figure 1.** Flowsheet of the patient selection process for analysis.

HD, hemodialysis; PD, peritoneal dialysis.

**Table 1.** Baseline patient characteristics

Characteristic	Total	1990–1999	2000–2009	2010–2019	p-value	p for trend
No. of patients	1,203	270	481	452		
Age (yr)					0.02	0.006
18–40	390 (32.4)	74 (27.4)	150 (31.2)	166 (36.7)		
41–60	560 (46.6)	137 (50.7)	215 (44.7)	208 (46.0)		
>60	253 (21.0)	59 (21.9)	116 (24.1)	78 (17.3)		
Male sex	701 (58.3)	163 (60.4)	289 (60.1)	249 (55.1)	0.23	0.12
Diabetes mellitus	345 (28.9)	58 (21.7)	165 (34.3)	122 (27.3)	0.001	0.31
Hypertension	877 (73.3)	59 (22.1)	446 (92.7)	372 (82.9)	<0.001	<0.001
Cardiovascular disease	216 (18.1)	12 (4.5)	144 (29.9)	60 (13.4)	<0.001	0.13
Davies comorbidity score					<0.001	0.06
Low risk (0)	580 (55.4)	69 (59.0)	236 (49.1)	275 (61.1)		
Medium risk (1, 2)	405 (38.7)	48 (41.0)	199 (41.4)	158 (35.1)		
High risk ( $\geq 3$ )	62 (5.9)	0 (0)	45 (9.4)	17 (3.8)		

Data are expressed number only or number (%).

## Patient survival

A total of 230 patients (19.1%) died during the follow-up period. Common causes of death were infection (n = 55), cardiac disease (n = 38), and cerebrovascular disease (n = 17) (Table 2). The number of deaths due to cardiac disease and infection decreased from the 1990–1999 to the 2010–2019 cohort. Overall, the 5- and 8-year crude survival rates were 64% and 49%, respectively. The 5-year patient survival rate improved substantially over time (64% for the 1990–1999 cohort vs. 93% for the 2010–2019 cohort) (Table 3, Fig. 2). Adjusted survival data also showed the same pattern. We analyzed the trend of patient survival in participants who continued PD for more than 5 years, and this group also demonstrated similar results (Supplementary Table 1, available online). Compared to the 1990–1999 cohort, the risk of all-cause mortality decreased by 58.0% for the 2000–2009 cohort and by 82.6% for the 2010–2019 cohort (multivariable model) (Table 4). Compared to the 1990–1999 cohort, the risks of death from peritonitis and cardiac death were reduced by 77.1% and 64.3%, respectively, in the 2010–2019 cohort (multivariable model) (Table 4). We performed subgroup analyses stratified by age (18–40, 41–60, or >60 years), sex (male or female), DM (yes or no), and Davies comorbidity scores (0 or >0). For each stratum, we analyzed the risk of all-

cause mortality for the 2010–2019 cohort compared with the 1990–1999 cohort. Overall, for all the subgroup strata with the exception of the younger patients (18–40 years), the risk of all-cause death was significantly lower for the 2010–2019 cohort compared with the 1990–1999 cohort (Fig. 3).

## Technique survival

A total of 397 (33.0%) patients experienced PD technique failure. Among these patients, the median elapsed times to technique failure were 3.5, 3.9, and 3.6 years for the 1990–1999, 2000–2009, and 2010–2019 cohorts, respectively. The 5-year technique survival did not improve over time (77% vs. 71%; Fig. 2). Compared with the 1990–1999 cohort, the risk of technique failure was higher in the 2000–2019 cohort (Table 5). However, there was no difference in risk between the 2000–2009 and 2010–2019 cohorts. Common causes of technique failure were infection-related technical failures (42.3%) and problems with solute/water clearance (22.7%) (Table 6). Over time, the proportion of infection-related technical failures decreased from 56.1% to 36.8%, while the proportion of solute/water clearance problems and psychosocial/medical technique failures increased from the 1990–1999 cohort to the 2010–2019 cohort.

**Table 2. Causes of death**

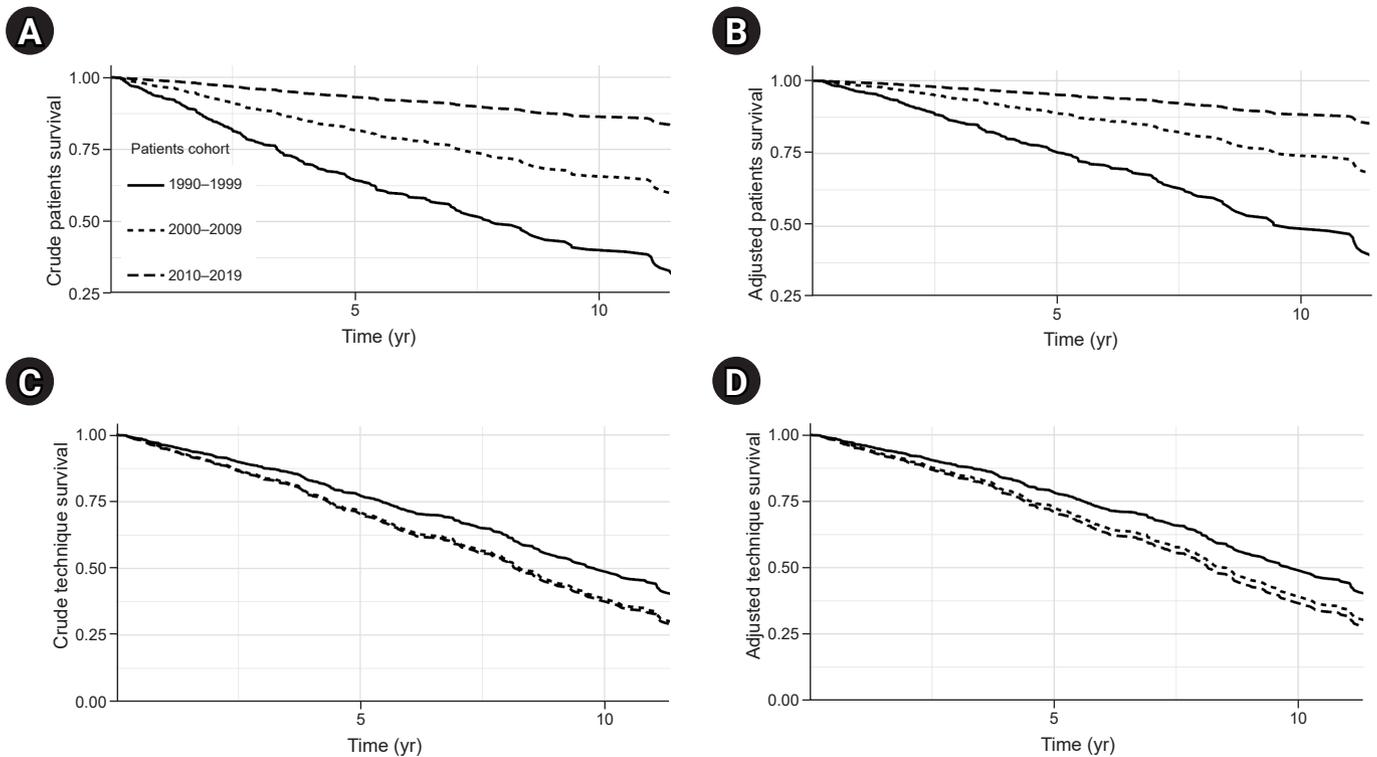
Variable	Total	1990–1999	2000–2009	2010–2019
Death/patient	230/1,203	112/270	94/481	24/452
Cardiac disease	38 (3.2)	14 (5.2)	17 (3.5)	7 (1.5)
Cerebrovascular disease	17 (1.4)	7 (2.6)	8 (1.7)	2 (0.4)
Infection	55 (4.6)	21 (7.8)	28 (5.8)	6 (1.3)
Malignancy	6 (0.5)	3 (1.1)	2 (0.4)	1 (0.2)
Sudden death	4 (0.3)	0 (0)	2 (0.4)	2 (0.4)
Others	17 (1.4)	5 (1.9)	9 (1.9)	3 (0.7)
Unknown causes	93 (7.7)	62 (23.0)	28 (5.8)	3 (0.7)

Data are presented as number only or number (%); the % is the ratio to the number of participants in each cohort.

**Table 3. Patient survival rates by cohort**

Year of cohort	Crude survival		Adjusted survival <sup>a</sup>	
	Five-year survival (%)	Eight-year survival (%)	Five-year survival (%)	Eight-year survival (%)
1990–1999	64	49	75	60
2000–2009	82	72	89	81
2010–2019	93	89	95	91
Overall	64	49	80	66

<sup>a</sup>Adjusted for age, sex, and diabetes mellitus status.



**Figure 2. Survival rates by cohort.** (A) The crude patient survival rate. (B) The adjusted patient survival rate. (C) The crude technical survival rate. (D) The adjusted technical survival rate. The adjusted survival rate was adjusted for age, sex, and diabetes mellitus status.

**Table 4. The risk of all-cause mortality and cause-specific mortality by cohort**

Year of cohort	Univariable		Multivariable <sup>a</sup>	
	HR (95% CI)	p-value	HR (95% CI)	p-value
<b>Risk of all-cause death</b>				
1990–1999	1 (Reference)		1 (Reference)	
2000–2009	0.46 (0.35–0.61)	<0.001	0.42 (0.32–0.55)	<0.001
2010–2019	0.16 (0.10–0.25)	<0.001	0.17 (0.11–0.27)	<0.001
<b>Risk of death from peritonitis</b>				
1990–1999	1 (Reference)		1 (Reference)	
2000–2009	0.68 (0.32–1.46)	0.33	0.54 (0.25–1.17)	0.12
2010–2019	0.24 (0.07–0.85)	0.03	0.23 (0.06–0.83)	0.03
<b>Risk of cardiac death</b>				
1990–1999	1 (Reference)		1 (Reference)	
2000–2009	0.65 (0.32–1.32)	0.23	0.59 (0.29–1.20)	0.15
2010–2019	0.33 (0.13–0.82)	0.02	0.36 (0.14–0.89)	0.03

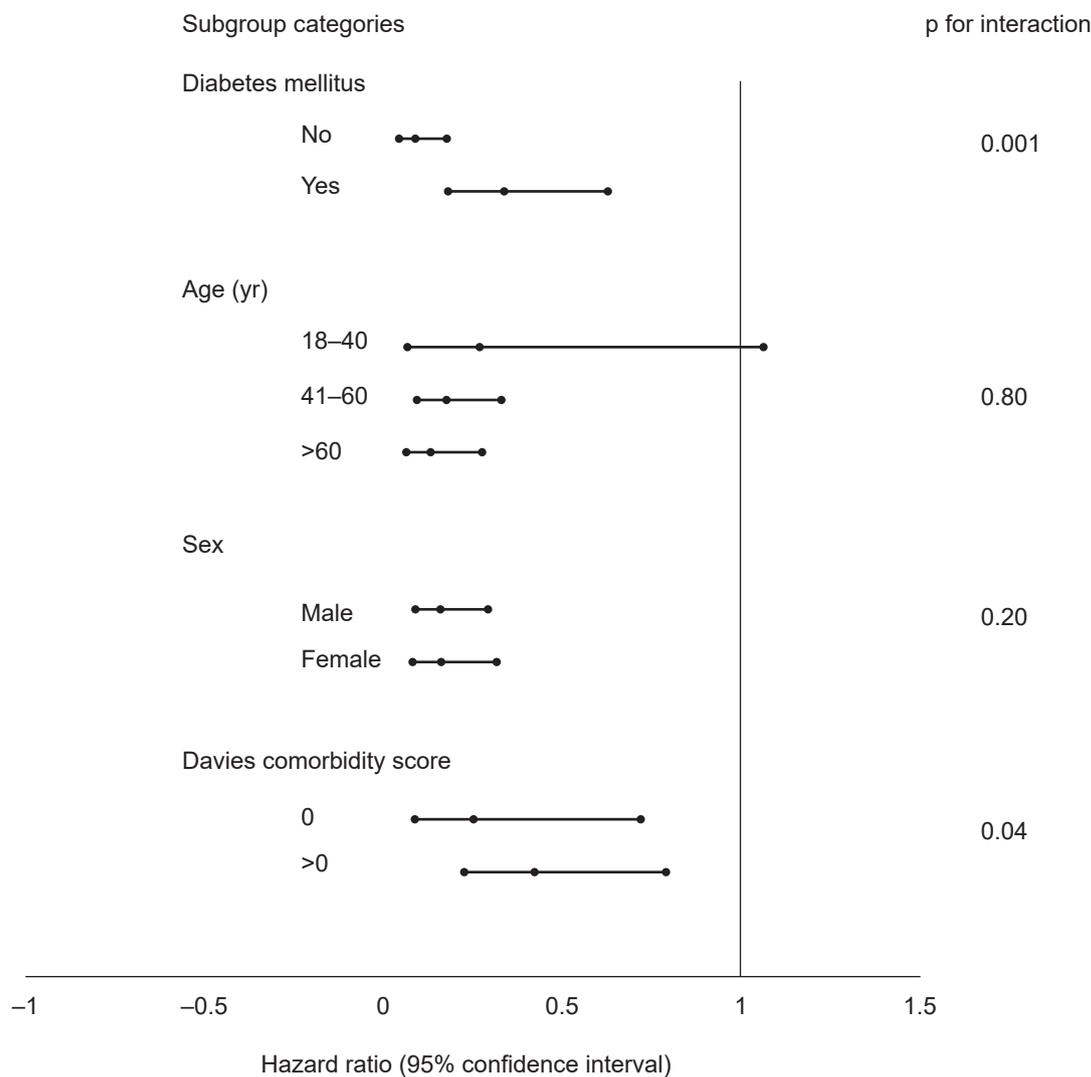
CI, confidence interval; HR, hazard ratio.

<sup>a</sup>Adjusted for age, sex, and diabetes mellitus status.

### Peritonitis

There were 879 episodes of peritonitis from 2000 until 2019 (overall incidence, 0.193 episodes per patient-year).

Over time, the incidence of peritonitis significantly decreased from 0.278 episodes per patient-year in 2000–2004 to 0.162 episodes per patient-year in 2015–2019 (Fig. 4A). For cause-specific peritonitis, the incidence due to coagu-



**Figure 3.** Stratified subgroup analysis for the risk of all-cause death for the 2010–2019 vs. the 1990–1999 cohort. For the Davies comorbidity score, ‘0’ denotes low risk, while ‘>0’ denotes a medium or high risk.

**Table 5.** Risk of technique failure by cohort

Year of cohort	Univariable		Multivariable <sup>a</sup>	
	HR (95% CI)	p-value	HR (95% CI)	p-value
1990–1999	1 (Reference)		1 (Reference)	
2000–2009	1.41 (1.08–1.85)	0.01	1.41 (1.07–1.85)	0.01
2010–2019	1.46 (1.08–1.96)	0.01	1.52 (1.12–2.05)	0.007

CI, confidence interval; HR, hazard ratio.

<sup>a</sup>Adjusted for age, sex, and diabetes mellitus status.

lase-negative *Staphylococcus* increased slightly in the 2010s but decreased remarkably in general. In contrast, the incidence of peritonitis associated with enteric gram-negative organisms (such as *Escherichia coli* and others) did not change (Fig. 4B).

### Discussion

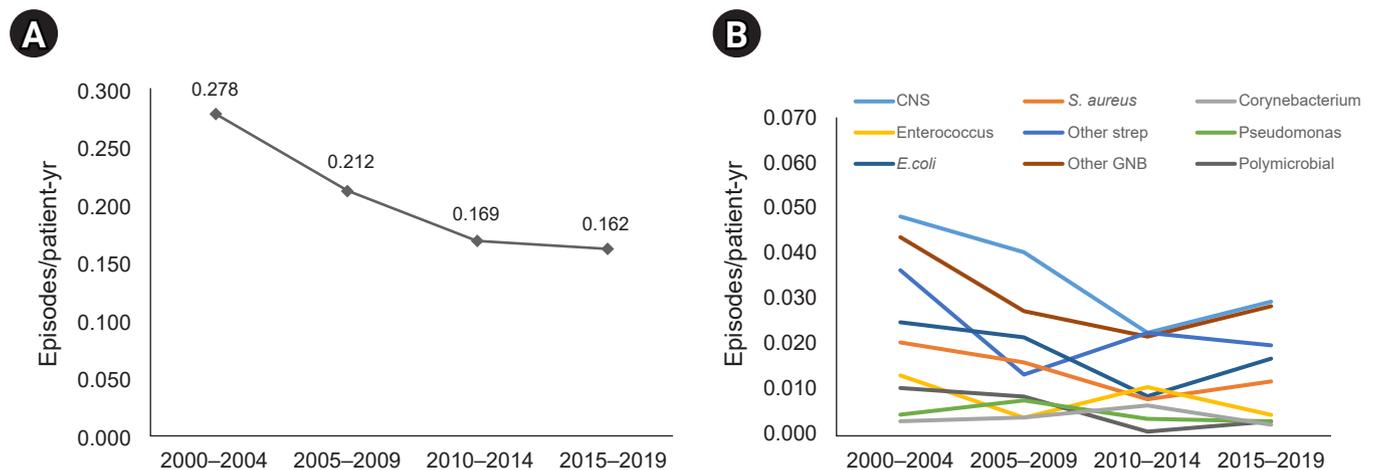
The temporal trend of PD outcomes in this study showed that the patient survival and the peritonitis rates have significantly improved over the last 30 years at our PD center. As

**Table 6. Causes of technique failure**

Cause	Total (n = 397)	1990–1999 (n = 82)	2000–2009 (n = 190)	2010–2019 (n = 125)
Infection-related	168 (42.3)	46 (56.1)	76 (40.0)	46 (36.8)
Catheter-related	19 (4.8)	5 (6.1)	9 (4.7)	5 (4.0)
Solute/water clearance problem	90 (22.7)	8 (9.8)	46 (24.2)	36 (28.8)
Peritoneal leaks/hernias	10 (2.5)	0 (0)	9 (4.7)	1 (0.8)
Psychosocial/medical	44 (11.1)	1 (1.2)	21 (11.1)	22 (17.6)
Risk of or diagnosis of EPS	12 (3.0)	2 (2.4)	7 (3.7)	3 (2.4)
Other causes	54 (13.6)	20 (24.4)	22 (11.6)	12 (9.6)

Data are presented as number (%).

EPS, encapsulating peritoneal sclerosis.



**Figure 4. Temporal trends in the incidence of peritonitis.** (A) The overall incidence of peritonitis. (B) The cause-specific incidence of peritonitis.

CNS, coagulase-negative *Staphylococci*; *E. coli*, *Escherichia coli*; GNB, gram-negative bacteria; *S. aureus*, *Staphylococcus aureus*; strep, *Streptococcus*.

shown in Fig. 3, the survival improvement for the 2010–2019 cohort was significant among middle-aged and elderly patients regardless of sex, DM status, or comorbidity score. In particular, the adjusted patient survival rates for the 2010–2019 incident cohort at our center were 95% after 5 years and 91% after 8 years, which are far superior to any outcomes recently reported for any other institution [28–33].

The two most common causes of death in our study were cardiac disease and infection, including peritonitis. However, the number of deaths due to cardiac disease and infection decreased from the 1990–1999 to the 2010–2019 cohorts (Table 2). Temporal improvement in patient survival on PD is consistent with trends from other studies [30,31]. These improvements in patient survival may reflect the continuing development of PD as a therapy as well as better care of any comorbid diseases.

In 2002, we launched an MPE program for advanced CKD patients and their families. The education team was comprised of nephrologists, dialysis nurses, pharmacists, dietitians, and social workers. Each session provided education on normal kidney function, pathophysiologic alterations in CKD, diet, and medication. Additionally, unbiased information about RRT options was delivered. Any patients who were considering PD as their first RRT were encouraged to meet the nursing staff at the PD center to obtain more information about PD therapy. Since the MPE program began in 2002, the number of patients who choose PD as their initial RRT modality has increased dramatically each year (Supplementary Fig. 1). Although there was also a nationwide increase in the total incident PD patients in the same period [34], we suspect that this increase may be partly due to the initiation of the MPE program. We also previously reported

that the MPE reduced the risk for unplanned urgent dialysis, cardiovascular and infection complications, and hospitalization [22].

As a home dialysis treatment, PD requires a comprehensive understanding of the therapy and self-management by the patient; these abilities may be associated with patient socioeconomic status and, crucially, education level. Because we offer the MPE program and comprehensive training at our PD center, we were able to retrospectively analyze the impact of lower education attainment on various PD outcomes in 655 incident PD patients [23]. Although a lower education attainment level was a significant risk factor for peritonitis and technique failure, it was not associated with increased mortality in PD patients. Therefore, we have shown that comprehensive training and multidisciplinary education provided by the PD center could overcome low education attainment among PD patients.

The 2020 ISPD PD Practice Recommendations focused on high-quality, goal-directed PD [35], which emphasized establishing realistic care goals to maintain HRQOL for PD patients through individualized care and shared decision-making. In a recent publication, we reported that about 50% of our PD patients from the SNUH PD registry were initially prescribed a low-dose prescription that was increased incrementally as their residual renal function declined. Our analyses found no differences in patient survival or technique survival between the incremental PD and full-dose PD groups [36].

Based on our data, although patient survival significantly improved, the risk of technique failure did not get better over time. This result is consistent with other reports from a large registry of PD patients, which showed that PD technique survival did not improve, whereas patient survival rates significantly improved over time [29,30]. Although we observed a dramatic reduction in the incidence of peritonitis over time, peritonitis still remains the most common cause of technique failure. This relationship might be due to the relative increase of severe peritonitis cases or to the more aggressive attitude of physicians toward PD catheter removal and transfer to HD for fear of peritonitis-related complications, such as membrane failure or EPS. Other major causes of technique failure included problems with solute/water clearance, psychosocial/medical technical failures, catheter-related problems, EPS risk or diagnosis, and peritoneal leaks or hernias (Table 6). Table 6 shows a gradual decrease

in infection-related technique failures, while problems with solute/water clearance and psychosocial/medical issues increased relative to the cause of technique failure. Generally, the rate of technique failure is at its highest during the first 3 months after PD initiation. However, we excluded patients with a PD duration <3 months from our analyses. Therefore, this study was unable to evaluate the incidence and causes of early PD failure. A vigilant and strategic approach to target specific causes of technique failure and to prolong technique survival is warranted, both within individual centers and in liaison with an international research consortium [26].

Peritonitis is the main factor that contributes to death and technique failure in PD patients. The 2016 ISPD guidelines recommend that the overall peritonitis incidence be no more than 0.5 episodes per year [27]. At our center, there was a significant drop in the overall peritonitis incidence over time (Fig. 4A). As shown in Fig. 4B, the incidence of coagulase-negative *Staphylococcus*, which is a normal skin flora and is associated with touch contamination, has been reduced over time due to enforced patient training. However, the relative incidence of enteric gram-negative organisms, which are more likely to lead to treatment failure, did not change during the observation period. More attention should be paid to the prevention of peritonitis due to enteric microorganisms in the future.

We noted the importance of regular retraining at home, where most PD exchanges are carried out, to prevent PD-related infection. We conducted a clinical trial comparing the benefit of frequent versus conventional home visits by dialysis nurses [24]. Exit-site infection and any PD-related infections for the frequent-visit group decreased over time, while those for the conventional group increased after one year. In the older subgroup (age  $\geq 60$  years), frequent retraining visits were associated with significantly longer peritonitis-free survival times. Therefore, we showed that frequent retraining at home reduced the risk of PD-related infections.

Our study was limited by the fact that it was a single-center analysis. Some laboratory data and detailed information on peritonitis between 1990 and 1999 were not available. Compared with other studies [30,32], our patients were relatively younger, which probably contributed to the better outcomes in our study. The remarkable improvement in PD outcomes over time at our PD center may not be fully generalizable to all practice settings, especially to centers that do not have adequate support infrastructure, such as a patient education

system, trained nephrologists, and a dedicated PD nursing staff. Unlike the substantial improvement in the patient survival and the peritonitis rates, the risk of technique failure did not improve over time in our analyses. However, based on the large number of PD patients who demonstrated persistent improvement over three decades, this study indicated that PD is an excellent therapy for patients with ESRD and also that outcomes continuously improved within a well-organized, multidisciplinary care system. Future research and efforts should aim not only to improve patient survival but also to increase technique survival, improve cardiovascular and peritonitis treatment outcomes, and to enhance quality of life in PD.

In conclusion, our findings suggest that PD is an excellent RRT and is consistently improving over time. Establishing an adequate system and infrastructure for high-quality PD therapy is important for improving PD outcomes.

### Conflicts of interest

Kook-Hwan Oh reports grants from Fresenius Medical Care, Korea and Baxter, Korea. The other authors have no conflicts of interest to declare.

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### Authors' contributions

Conceptualization: KHO, CA  
Investigation, Data curation, Formal analysis: MK, YLK, EK, KHO, YCK, DKK, HL, SSH, KWJ, YSK, CA, HR  
Funding acquisition: KHO  
Visualization: MK, YLK

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### References

1. Bello AK, Levin A, Lunney M, et al. Status of care for end stage kidney disease in countries and regions worldwide: international cross sectional survey. *BMJ* 2019;367:l5873.
2. Korevaar JC, Feith GW, Dekker FW, et al. Effect of starting with hemodialysis compared with peritoneal dialysis in patients new on dialysis treatment: a randomized controlled trial. *Kidney Int* 2003;64:2222–2228.
3. Heaf JG, Løkkegaard H, Madsen M. Initial survival advantage of peritoneal dialysis relative to haemodialysis. *Nephrol Dial Transplant* 2002;17:112–117.
4. Weinhandl ED, Foley RN, Gilbertson DT, Arneson TJ, Snyder JJ, Collins AJ. Propensity-matched mortality comparison of incident hemodialysis and peritoneal dialysis patients. *J Am Soc Nephrol* 2010;21:499–506.
5. Lukowsky LR, Mehrotra R, Kheifets L, Arah OA, Nissenson AR, Kalantar-Zadeh K. Comparing mortality of peritoneal and hemodialysis patients in the first 2 years of dialysis therapy: a marginal structural model analysis. *Clin J Am Soc Nephrol* 2013;8:619–628.
6. He L, Liu X, Li Z, et al. Rate of decline of residual kidney function before and after the start of peritoneal dialysis. *Perit Dial Int* 2016;36:334–339.
7. Neumann D, Mau W, Wienke A, Girndt M. Peritoneal dialysis

- is associated with better cognitive function than hemodialysis over a one-year course. *Kidney Int* 2018;93:430–438.
8. Nakayama M, Ishida M, Ogihara M, et al. Social functioning and socioeconomic changes after introduction of regular dialysis treatment and impact of dialysis modality: a multi-centre survey of Japanese patients. *Nephrology (Carlton)* 2015;20:523–530.
  9. Hsu CC, Huang CC, Chang YC, Chen JS, Tsai WC, Wang KY. A comparison of quality of life between patients treated with different dialysis modalities in Taiwan. *PLoS One* 2020;15:e0227297.
  10. The U.S. Centers for Medicare & Medicaid Services (CMS). End Stage Renal Disease (ESRD) Prospective Payment System (PPS) [Internet]. Baltimore, MD: CMS; 2021 [cited 2021 Apr 15]. Available from: <https://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/ESRDpayment/index>.
  11. Saran R, Robinson B, Abbott KC, et al. US renal data system 2019 annual data report: epidemiology of kidney disease in the United States. *Am J Kidney Dis* 2020;75(1 Suppl 1):A6–A7.
  12. Shaldon S, Koch KM, Quellhorst E, Lonnemann G, Dinarello CA. CAPD is a second-class treatment. *Contrib Nephrol* 1985;44:163–172.
  13. Berns JS. A survey-based evaluation of self-perceived competency after nephrology fellowship training. *Clin J Am Soc Nephrol* 2010;5:490–496.
  14. Rope RW, Pivert KA, Parker MG, Sozio SM, Merrell SB. Education in nephrology fellowship: a survey-based needs assessment. *J Am Soc Nephrol* 2017;28:1983–1990.
  15. Wang Q, Hu KJ, Ren YP, et al. The association of individual and regional socioeconomic status on initial peritonitis and outcomes in peritoneal dialysis patients: a propensity score-matched cohort study. *Perit Dial Int* 2016;36:395–401.
  16. Khalid U, Zaidi A, Cheang A, et al. 'Educational' deprivation is associated with PD peritonitis. *Perit Dial Int* 2018;38:251–256.
  17. Tao S, Zeng X, Liu J, Fu P. Socioeconomic status and mortality among dialysis patients: a systematic review and meta-analysis. *Int Urol Nephrol* 2019;51:509–518.
  18. Chung SH, Heimbürger O, Lindholm B, Lee HB. Peritoneal dialysis patient survival: a comparison between a Swedish and a Korean centre. *Nephrol Dial Transplant* 2005;20:1207–1213.
  19. Afolalu B, Troidle L, Osayimwen O, Bhargava J, Kitsen J, Finkelstein FO. Technique failure and center size in a large cohort of peritoneal dialysis patients in a defined geographic area. *Perit Dial Int* 2009;29:292–296.
  20. Plantinga LC, Fink NE, Finkelstein FO, Powe NR, Jaar BG. Association of peritoneal dialysis clinic size with clinical outcomes. *Perit Dial Int* 2009;29:285–291.
  21. Schaubel DE, Blake PG, Fenton SS. Effect of renal center characteristics on mortality and technique failure on peritoneal dialysis. *Kidney Int* 2001;60:1517–1524.
  22. Cho EJ, Park HC, Yoon HB, et al. Effect of multidisciplinary pre-dialysis education in advanced chronic kidney disease: Propensity score matched cohort analysis. *Nephrology (Carlton)* 2012;17:472–479.
  23. Kim HJ, Lee J, Park M, et al. Lower education level is a risk factor for peritonitis and technique failure but not a risk for overall mortality in peritoneal dialysis under comprehensive training system. *PLoS One* 2017;12:e0169063.
  24. Chang JH, Oh J, Park SK, et al. Frequent patient retraining at home reduces the risks of peritoneal dialysis-related infections: a randomised study. *Sci Rep* 2018;8:12919.
  25. Davies SJ, Phillips L, Naish PF, Russell GI. Quantifying comorbidity in peritoneal dialysis patients and its relationship to other predictors of survival. *Nephrol Dial Transplant* 2002;17:1085–1092.
  26. Perl J, Davies SJ, Lambie M, et al. The peritoneal dialysis outcomes and practice patterns study (PDOPPS): unifying efforts to inform practice and improve global outcomes in peritoneal dialysis. *Perit Dial Int* 2016;36:297–307.
  27. Li PK, Szeto CC, Piraino B, et al. ISPD peritonitis recommendations: 2016 update on prevention and treatment. *Perit Dial Int* 2016;36:481–508.
  28. Han SH, Lee SC, Ahn SV, et al. Improving outcome of CAPD: twenty-five years' experience in a single Korean center. *Perit Dial Int* 2007;27:432–440.
  29. Peng Y, Ye H, Yi C, et al. Changes in outcomes over time among incident peritoneal dialysis patients in Southern China. *Perit Dial Int* 2019;39:382–389.
  30. Perl J, Wald R, Bargman JM, et al. Changes in patient and technique survival over time among incident peritoneal dialysis patients in Canada. *Clin J Am Soc Nephrol* 2012;7:1145–1154.
  31. Mehrotra R, Chiu YW, Kalantar-Zadeh K, Bargman J, Vonesh E. Similar outcomes with hemodialysis and peritoneal dialysis in patients with end-stage renal disease. *Arch Intern Med* 2011;171:110–118.
  32. Abe M, Hamano T, Hoshino J, et al. Predictors of outcomes in patients on peritoneal dialysis: a 2-year nationwide cohort study. *Sci Rep* 2019;9:3967.
  33. Hwang SD, Lee JH, Jhee JH, Song JH, Kim JK, Lee SW. Impact of body mass index on survival in patients undergoing peritoneal dialysis: analysis of data from the Insan Memorial End-Stage Renal Disease Registry of Korea (1985–2014). *Kidney Res Clin Pract*

- 2019;38:239–249.
34. Jin DC, Han JS. Renal replacement therapy in Korea, 2012. *Kidney Res Clin Pract* 2014;33:9–18.
35. Brown EA, Blake PG, Boudville N, et al. International Society for Peritoneal Dialysis practice recommendations: prescribing high-quality goal-directed peritoneal dialysis. *Perit Dial Int* 2020;40:244–253.
36. Lee Y, Chung SW, Park S, et al. Incremental peritoneal dialysis may be beneficial for preserving residual renal function compared to full-dose peritoneal dialysis. *Sci Rep* 2019;9:10105.