Original Article

Optimizing Peritoneal Dialysis with Peritoneal Equilibration Test: Membrane Characterization to Tailored Therapy

Zaineb Kaouiri[1], Meryem Assem[2], Nadia Sakout[1], Tarik Bouattar[1], Naima Ouzeddoun[1], Loubna Benamar[1]

[1]Department of Nephrology–Dialysis–Kidney Transplantation, Ibn Sina Hospital, Rabat, Morocco. Faculty of Medicine and Pharmacy, Mohammed V University, Rabat, [2]Department of Nephrology, Mohammed VI University Hospital, Tangier, Morocco, Faculty of Medicine and Pharmacy, Mohammed VI University, Tangier, Morocco

Corresponding author:
Zaineb Kaouiri, Department of Nephrology–Dialysis–Kidney Transplantation, Ibn Sina Hospital, Rabat, Morocco. Faculty of Medicine and Pharmacy, Mohammed V University, Rabat, Morocco. E-mail: zaineb.kaouiri@gmail.com

Abstract

Background: The peritoneal equilibration test (PET) assesses peritoneal membrane characteristics in patients undergoing peritoneal dialysis (PD). This study aims to assess the prevalence of PET testing, describe membrane characteristics, and evaluate PET's impact on PD prescriptions and patient outcomes. **Materials and Methods:** This retrospective cohort study included all PD patients treated at our center between 2006 and 2023. We analyzed membrane characteristics, PET result-based changes in PD prescriptions, and PET prognostic value for PD discontinuation, cardiovascular events, mortality, and hospitalizations. **Results:** Of 240 patients, 82 (33%) had a PET, with a decrease in prevalence after 2017. Membrane characteristics differed between patients with fast and slow peritoneal solute transfer rates, influencing PD prescription, particularly ultrafiltration management. Indication-based PET led to more targeted prescription adjustments. FTs tend to be hospitalized more frequently than STs (74% vs. 56%, p=0.115). Cardiovascular events affected 50.7% of patients, with no significant difference between the two groups (p=0.844). We saw that 30% of patients discontinued PD, with no notable difference between RTs and STs. All-cause mortality was recorded in 37.8% of patients, with more among FTs (40%) compared to STs (30%), although this difference was not statistically significant (p=0.392). **Conclusion:** Indication-based PET allows tailored adjustments in PD prescriptions without compromising patient outcomes. PET remains a valuable tool with prognostic value for PD management.

Keywords: *Peritoneal dialysis, Peritoneal equilibration test, Peritoneal solute transfer*

Introduction

Peritoneal dialysis (PD), a kidney replacement therapy (KRT), offers greater flexibility and improved quality of life for patients with end-stage kidney disease (ESKD). Unlike hemodialysis (HD), PD uses the peritoneum to remove waste and excess fluid.[1]

The peritoneal membrane (PM) has varying permeability properties and may also undergo changes due to dialysis fluid exposure, technique-related infectious complications, and dialysis durations. Understanding the PM functioning in each patient is essential for optimizing dialysis outcomes, thus improving both survival and technique longevity.

The peritoneal equilibration test (PET) is most widely used to assess the transport and ultrafiltration characteristics of the PM. Standardized, reproducible, and non-invasive, it is an essential tool for monitoring peritoneal changes in PD patients.[2]

The study's primary objective was to evaluate PET's impact on prescription changes in PD. The secondary objective was to determine PET's prognostic value in terms of PD discontinuation, cardiovascular events, mortality, and hospitalizations.

Materials and Methods

We conducted a retrospective, descriptive, and analytical study from 2006 to 2023 at our center, including all patients on PD who underwent a PET. The study does not require ethical approval, as it is a retrospective. Patient consent was obtained for an anonymous publication. Patients on continuous ambulatory PD (CAPD) with residual kidney function were treated with incremental dialysis—starting with two exchanges/day and increasing the number and/or adjusting the dialysate concentration

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as needed. For anuric patients, three exchanges were adopted from the beginning.

Patients on automated PD (APD) were given a maximum of 11 hours with a variable number and duration of cycles, depending on the patients' residual kidney function. The "empty abdomen" approach was not adopted.

All patients starting PD before 2017 underwent the PET between 6 weeks and 3 months after beginning dialysis. After 2017, the PET was only performed in the presence of clinical or biological indications, such as insufficient ultrafiltration (UF), inadequate dialysis, low KT/V (weekly urea clearance divided by total body water), and/or low weekly creatinine clearance.

Before 2021, PET required a 2.27% dextrose-based exchange as described by Twardowski in 1987. The main outcome was expressed as the Dialysate/Plasma (D/P) creatinine ratio after a 4-hour dwell. Patients were classified as high, moderate-high, low, or moderate-low transporters. A 4-hour 3.86% test was performed to assess the UF capacity of some patients' PM.

The modified PET was adopted following new recommendations by the International Society for Peritoneal Dialysis (ISPD), 2021. It uses a 3.86% dextrose solution. It classifies patients into fast peritoneal solute transfer rate (FT) and slow peritoneal solute transfer rate (ST) if the D/P creatinine ratio at 4 hours is >0.65 and <0.65, respectively. It also diagnoses UF failure using a 4-hour UF volume (< 400 mL) and intrinsic PM dysfunction by measuring dialysate sodium after a 1-hour dwell: dip-sodium. A sodium drop of <5 mmol/L indicates UF insufficiency.

To standardize the results of different PETs (before and after 2021), pre-2021 PET results were reclassified according to the new ISPD criteria. Patients were categorized as FT and ST if D/P creatinine at 4 hours was > 0.65 and < 0.65, respectively. This reclassification enabled consistent data comparison and descriptive and analytical studies of the results.

Clinical and biological data were collected from medical records on pre-established forms. We compared demographic, clinical, and technical characteristics of both groups (FT and ST) and analyzed PET's impact on prescription modifications in PD. We also studied cardiovascular event frequency, all-cause mortality, PD discontinuation, and the number of hospitalizations in both patient groups.

Data were entered into Microsoft Excel 2016 and analyzed using the Jamovi software. Quantitative variables were presented as medians with interquartile ranges. Qualitative variables were expressed as proportions and/or percentages. Continuous and qualitative variables were compared using the Mann-Whitney U test and Chi-square test or Fisher's exact test, respectively. A p-value < 0.05 was considered statistically significant.

Results

Of the 240 patients, 82 (33%) underwent a PET. PET prevalence before and after 2017 was 100% and 13.3%, respectively. Median age of the patients was 46.5 years [30.3-60], with M:F of 1.56 and a median Charlson comorbidity score of 2 [2-3], reflecting a population with a moderate burden of morbidity.

Regarding dialysis modality, 17.5% and 82.5% of patients used APD and CAPD, respectively. Among CAPD patients, 71.2% performed two exchanges/day, with a mean residual kidney function of 4.58 mL/min and a mean urine output of 1.6 L/day, while 28.8% performed three exchanges/day with a mean residual kidney function of 3.51 mL/min and a mean urine output of 1.2 L/day. The 3.86% dextrose solution was used when signs of overload necessitated significant UF, only for a limited duration, regardless of the PD modality.

PET was performed at a median of 10.5 months [3-25.5] after the start of PD. The PET was performed at a median of 2.36 months and 26.6 months [1.5-2.9] for patients starting PD before and after 2017, respectively [7.25-48].

The underlying causes of nephropathy among patients varied. Tubulointerstitial nephropathies (20.7%), followed by diabetic nephropathies (19.5%), and undetermined nephropathies (19.5%), and glomerular nephropathies (17.1%) were the most prevalent. Hereditary and vascular nephropathies represented 11% and 12.2% of cases, respectively [Table 1].

Based on PET results, there were 72.5% FT and 27.5% ST patients. FTs had a higher diabetes prevalence compared to STs (25% versus 13%). In terms of cardiovascular disease, 50% of patients had a history of heart disease, with similar proportions between FT and ST [Table 1].

Impact of PET on PD prescription

PET resulted in an increase in the daily exchanges in 41.7% of patients on CAPD, without exceeding three exchanges/day. The dialysate concentration was adjusted in 13.4% of patients [Table 2]. Specifically, 12.5% of CAPD patients had switched their dialysate concentration to a more hypertonic solution or Icodextrin, and the daily exchange number in 39% increased from two to three, demonstrating PET's direct impact on adjusting the prescription to match the patient's PM permeability better.

PET modified the number of cycles and dialysate concentration in 60% and 20% of patients with APD, respectively [Table 3]. The dialysate was concentrated or adjusted to icodextrin in 18% of patients and the number of cycles increased from 4 to 5 or 6/night in 54% of FTs. The number of cycles decreased in 75% of STs.

Table 1: Demographic, clinical and technical data for both groups: FT and ST

Variables	Total (n=82)	Fast transporters (n=59)	Slow transporters (n=23)	P value
Age (years)	46 (30.3,60)	44 (29,58)	50 (35.5,65)	0.350
Sex (M/F)	48/34	34/25	14/9	0.789
BMI (kg/m²)	24.3 (21.3,26)	23.7 (21,26)	25.6 (23,30)	0.147
Charlson score	2 (2,3)	2 (2,3)	2 (2,3)	0.890
High blood pressure	63 (76.8%)	46 (78%)	17 (74%)	0.696
Diabetes	18 (22%)	15 (25%)	3 (13%)	0.232
Cardiopathy	41 (50%)	30 (51%)	11 (49%)	0.806
Dyslipidemia	51 (62%)	36 (61%)	15 (65%)	0.640
Initial kidney disease				
Tubulo-interstitial	17 (20.7%)	14 (23.7%)	3 (13%)	0.607
Hereditary	9 (11%)	4 (6.7%)	5 (21.7%)	0.135
Diabetic	16 (19.5%)	13 (22%)	3 (13%)	0.670
Glomerular	14 (17.1%)	12 (20%)	2 (8.8%)	0.469
Vascular	10 (12.2%)	4 (8.3%)	6 (26%)	0.082
Undetermined	16 (19.5%)	12 (20.3%)	4 (17.4%)	0.607
Hemodialysis before PD	17 (21%)	11 (18%)	6 (26%)	0.457
Residual kidney function	4.12 (0,13)	3.86 (0,10)	4.81 (0,13)	0.337
Intraperitoneal pressure	17 (8,28)	17.4 (8,28)	15.8 (11,21)	0.518
CAPD/APD	67/15	48/11	19/4	0.895
Time PD-PET (months)	19.2 (2,96)	18.7 (2,96)	20.5 (2,60)	0.745
Number of peritonitis	2 (0,3)	2 (0,3)	2 (1,3)	0.780

BMI: Body mass index, PD: Peritoneal dialysis, CAPD: Continuous ambulatory peritoneal dialysis, APD: Automated peritoneal dialysis, PET: Peritoneal equilibration test, FT: Fast peritoneal solute transfer, ST: Slow peritoneal solute transfer

Table 2: PET impact on PD prescription in CAPD

PD modality	Parameter	Before PET	After PET	%FT (n=48)	%ST (n=19)
CAPD (n=67)	Dialysate concentration	1.36	2.27/Icodextrine	6 (12.5%)	3 (15.7%)
	Number of exchanges	2 exchanges	3 exchanges	19 (39%)	9 (47%)

PD: Peritoneal dialysis, CAPD: Continuous ambulatory peritoneal dialysis, PET: Peritoneal equilibration test, FT: Fast peritoneal solute transfer rate patients, ST: Slow peritoneal solute transfer rate patients

Table 3: PET impact on PD prescription in APD

PD modality	Parameter	Before PET	After PET	%FT (n=11)	%ST (n=4)
APD (n=15)	Dialysate concentration	1.36	2.27/Icodextrine	2 (18%)	1 (25%)
	Number of cycles	4	5/6	6 (54%)	0
		4	3	0	3 (75%)

PD: Peritoneal dialysis, APD: Automated peritoneal dialysis, PET: Peritoneal equilibration test, FT: Fast peritoneal solute transfer rate patients, ST: Slow peritoneal solute transfer rate patients

The PET changed CAPD to APD in 23.2% of patients, highlighting its importance in optimizing and personalizing dialysis prescriptions based on each patient's PM characteristics.

Before 2017, dialysate concentration adjustments were relatively modest in CAPD and APD. After 2017, these adjustments became more targeted and frequent, although these differences were not statistically significant (p=0.400, p=0.063, respectively). This suggests that PET had refined prescription personalization, thereby optimizing treatments according to the specific patient needs [Table 4].

Finally, although FTs required more frequent PD modality changes, these differences were not statistically significant (p=0.397). This proved a variation in PET's impact based on individual patient characteristics [Table 4].

Prognostic value of PET

We observed that FTs tend to be hospitalized more frequently than STs (74% vs. 56%, p=0.115). Cardiovascular events affected 50.7% of patients, with no significant difference between the two groups (p=0.844) [Table 5].

PD was discontinued in 30% of patients, with no notable difference between FTs and STs. All-cause mortality was recorded in 37.8% of patients, with a slightly higher proportion among FTs (40%) than STs (30%), although this difference was not statistically significant (p=0.392) [Table 5].

Discussion

PET is an essential tool for adjusting PD prescriptions according to individual PM characteristics like transport and ultrafiltration properties. In clinical practice, PET is performed based on indications, particularly in the

Table 4: PET impact on PD prescription before and after 2017

PD modality	Parameter	Total (n=82)	Before 2017 (n=50)	After 2017 (n=32)	P value
CAPD/APD	CAPD → APD	19 (23.2%)	10 (12.2%)	9 (11.1%)	0.397
CAPD (n=67)	Dialysate concentration	9 (13.4%)	4 (8.3%)	5 (26.3%)	0.400
Before 2017 (n=48)	Number of exchanges	28 (41.7%)	20 (41.6%)	8 (42.1%)	0.974
After 2017 (n=19)					
APD (n=15)	Dialysate concentration	3 (20%)	0 (0%)	3 (23%)	0.063
Before 2017 (n=2)	Number of cycles	9 (60%)	2 (100%)	7 (54%)	0.604
After 2017 (n=13)					

PD: Peritoneal dialysis, CAPD: Continuous ambulatory peritoneal dialysis, APD: Automated peritoneal dialysis, PET: Peritoneal equilibration test

Table 5: Patients' evolution according to their PET results

	Total (n=82)	FT (n=59)	ST (n=23)	P value
Hospitalization	57 (69%)	44 (74%)	13 (56%)	0.115
Cardiovascular events	37 (50.7%)	27 (46%)	10 (43%)	0.844
PD discontinuation	24 (30%)	17 (29%)	7 (30%)	0.827
Death	31 (37.8%)	24 (40%)	7 (30%)	0.392

PD: Peritoneal dialysis, FT: Fast peritoneal solute transfer rate patients, ST: Slow peritoneal solute transfer rate patients, PET: Peritoneal equilibration test

presence of clinical and/or biological abnormalities, such as insufficient UF or inadequate clearance. Recent ISPD guidelines confirm this approach, stating the importance of reserving PET for specific clinical situations rather than routine use.[3] Moreover, several studies report a variation in PET frequency between centers, often performed for targeted indications due to the significant logistical burden it imposes.[4] Indeed, conducting a PET requires time, human resources, logistics, and coordination among care teams, which limits its systematic everyday use.

PET was performed in 33% of patients. It was systematically conducted before 2017, then only in the presence of a clinical or biological indication. This change in practice followed the updated recommendations, which we fully agreed with and promptly adopted. Limiting PET to specific clinical indications was aligned with logistical considerations, as performing the test routinely placed a significant burden on resources. By reserving PET for targeted situations, we optimized treatment effectiveness and addressed the organizational challenges associated with its routine use.

Our study demonstrated a similarity between demographic and clinical characteristics of fast and slow transporters in PD. However, fast transporters tend to have a higher diabetes prevalence, which could influence PM characteristics and necessitate specific prescription adjustments. This observation is consistent with several previous studies showing an association between diabetes and increased peritoneal transport.[5]

The initial causes of nephropathy were varied, with glomerular and tubulointerstitial nephropathies being the most common. Vascular and hereditary nephropathies were also frequent, particularly among slow transporters. This distribution aligns with general epidemiological data of patients with PD. A study by Díaz Cuevas *et al.* showed a similar distribution of initial nephropathies among PD patients, highlighting the great etiological diversity as well as the impact of initial nephropathy on patient management.[6]

Regional variations in PET results have highlighted the influence of demographic, genetic, and environmental factors on PM characteristics. For instance, studies conducted in Costa Rica[7] and Canada[8] have reported PET profiles that differ significantly from the initial descriptions by Twardowski. These findings emphasize the importance of tailoring PD protocols to the specific characteristics of local patient populations. Our study reinforces the need for individualized treatment approaches and serves as a foundation for future prospective research aimed at refining these protocols within diverse healthcare settings.

PET is an essential tool for personalizing PD prescriptions. PET led to changes in dialysate concentration, PD modality, and the number of exchanges in a significant number of patients. These modifications are crucial for optimizing clearance and UF and improving patients' clinical and biological outcomes during follow-up. According to a study by Davies *et al.*, PET allows for the patient stratification based on transport capacity and corresponding prescription adjustment, which improves survival and reduces PD-related complications.[9]

PD discontinuation was observed in 30% of patients, with no notable difference between fast and slow transporters. This was comparable to previous literature, where PD discontinuation ranges from 20% to 40%.[10] The reasons for PD discontinuation include recurrent PD-associated peritonitis, insufficient UF, and mechanical complications. A study by Brown *et al*. showed that fast transporters have a higher risk of insufficient UF, which could explain their tendency to require more frequent therapeutic adjustments or even a higher risk of PD discontinuation.[11]

Regarding hospitalizations, 69% of the patients in our study had been hospitalized more than three times, with a non-significant trend showing that fast transporters were more often hospitalized than slow transporters. The increased complexity of managing fast transporters, requiring closer monitoring and more frequent adjustments to the PD prescription, could have caused this. A systematic

review by Johnson *et al.* also highlighted the need for intensive management to prevent hospitalization in fast transporters.[12]

Cardiovascular events affected 50.7% of patients. This high prevalence is consistent with literature that indicates an increased risk of cardiovascular morbidity in ESKD patients due to the accumulation of risk factors, such as hypertension, diabetes, and hyperlipidemia.[13] Our study did not find a significant difference between fast and slow transporters in terms of cardiovascular events, suggesting against transport characteristics being the primary determinant of cardiovascular events in these patients.

All-cause mortality was recorded in 37.8% of patients, with a slightly higher proportion among fast transporters (40%) compared to slow transporters (30%). Although this difference was not statistically significant, it is in line with the observations of Brimble *et al*., who showed that fast transporters have a slightly higher mortality rate, potentially due to complications related to insufficient UF and the more complex management of PD.[14]

The results of our study highlight the importance of PET in personalizing PD. Using PET not only optimizes PD prescriptions but also anticipates the necessary adjustments to improve clinical outcomes. Fast transporters require particular attention due to their higher prevalence of diabetes and more complex therapeutic needs. Clinicians should be vigilant about changes in PD modality, dialysate concentration, and the number of exchanges, especially in fast transporters.

To improve the management of PD patients, it is recommended to perform a PET whenever there is a clinical or biological indication of unsatisfactory clearance or insufficient UF, rather than systematically for all patients, as it is not indispensable in every case. This approach helps monitor changes in the PM's transport characteristics while focusing on patients who truly need it. Close monitoring of complications, particularly PD peritonitis and cardiovascular events, is also essential. Integrated management strategies, including patient education and close coordination between nephrologists and dialysis care teams, can improve outcomes and reduce hospitalizations.

Our study has several limitations. First, the study's retrospective nature may introduce selection bias, as data are collected from existing medical records, which may limit the accuracy of the available information and the completeness of the data. Furthermore, variations in practices between different centers and changes in prescription protocols before and after 2017 could complicate the interpretation and generalization of the results. Finally, the sample size, although representative, may not capture all possible variations in the studied population.

However, our study also offers several positive aspects. It provides valuable data on the impact of PET on the PD management, particularly regarding prescription modifications and long-term outcomes. Comparing data before and after 2017 highlights the effects of changes in clinical practices and enhances the understanding of PET's prognostic value. Moreover, the study contributes to existing literature by providing specific information in a particular clinical context, thereby enriching knowledge on PET's use in daily practice.

Conflicts of interest: There are no conflicts of interest.

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