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Original Article

Association Between Peritoneal Transport Changes and Arterial Stiffness Parameters in Peritoneal Dialysis Patients

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Abstract

Background: Alterations in peritoneal membrane transport characteristics are common in long-term peritoneal dialysis (PD) patients and may reflect underlying microvascular dysfunction. Such changes are commonly associated with peritonitis episodes, prolonged use of glucose-based dialysate, and microvascular injury to the peritoneal membrane, reflecting structural and functional deterioration of the peritoneum. Arterial stiffness, particularly measured via augmentation index (AIx) and pulse wave velocity (PWV), is a known morbidity and closely related to macro and microvascular disease in this population. However, the relationship between longitudinal changes in peritoneal transport and arterial stiffness remains unclear.

Methods: This retrospective observational cohort study included all adult patients who had initiated PD and underwent a baseline peritoneal equilibration test (PET), with a follow-up duration of at least two years. AIx and PWV were measured in all participants using a non-invasive method. Patients were categorized into two groups based on the stability of their PET classification: stable PET vs. changed PET. Demographic, clinical, laboratory, and arterial stiffness parameters (PWV and AIx) were compared between groups.

Results: There were no significant differences in age, sex, comorbidities, laboratory values, or dialysis and adequacy measures between the two groups. PWV values were comparable (9.3 ± 2.1 m/s vs. 9.3 ± 1.9 m/s; p = 0.90). However, the AIx was significantly higher in the changed PET group compared to the stable group (30.6 ± 10.2 vs. 23.0 ± 10.6; p = 0.02).

Conclusion: The findings indicate an associative relationship between peritoneal transport changes and increased small artery stiffness. AIx may serve as a sensitive, non-invasive indicator of microvascular alterations in PD patients. These associations should be interpreted cautiously, and prospective studies are warranted to confirm the temporal and mechanistic links.

Keywords: Peritoneal Dialysis, Peritoneal Equilibration Test (PET), Vascular Stiffness, Augmentation Index (AIx)

INTRODUCTION

Peritoneal dialysis (PD) is a home-based renal replacement therapy that provides hemodynamic stability and greater autonomy for patients with end-stage renal disease. The long-term efficacy of PD, however, largely depends on the maintenance of peritoneal membrane integrity, including solute transport and ultrafiltration capacity (1-3). Chronic exposure to glucose-based dialysates, persistent low-grade inflammation, and the accumulation of advanced glycation end-products (AGEs) can induce progressive structural alterations in the peritoneal membrane (4,5). These changes may not only compromise local peritoneal function but also contribute to systemic vascular dysfunction (6,7). All of these are causes that have been identified to date, but the cause of the change in peritoneal permeability has not yet been fully elucidated.

Arterial stiffness is a well-established predictor of cardiovascular morbidity and mortality (8-10). Non-invasive techniques such as pulse wave velocity (PWV) and augmentation index (AIx) have been widely employed for its assessment (13). Arterial stiffness arises from a combination of structural and cellular changes, including the replacement of elastic fibres in the arterial lamina with collagen, chronic low-grade inflammation within the arterial wall, endothelial dysfunction, phenotypic modulation of vascular

smooth muscle cells, and vascular calcification. These alterations collectively diminish arterial compliance, resulting in elevated systolic and reduced diastolic blood pressures, particularly during the early phases of disease progression. The consequent hemodynamic load on the left ventricle promotes left ventricular hypertrophy and contributes to the development of diastolic dysfunction (14-16). Non-invasive methods used to assess arterial stiffness include arterial tonometry, which plays an important role. In this context, PWV and AIx are prominent arterial tonometry techniques (17). PWV is calculated by dividing the time it takes for the pulse wave to travel between the arms and ankles by the distance between these points. AIx primarily reflects the stiffness of smaller and muscular arteries. Increased arterial stiffness leads to higher PWV, which in turn contributes to elevated AIx values through earlier wave reflections. Both PWV and AIx have been independently associated with adverse cardiovascular outcomes and increased all-cause mortality, particularly in patients undergoing dialysis (18-20). Numerous studies have demonstrated a significant positive correlation between arterial stiffness and inflammation in various patient populations, including those with chronic kidney disease (21). While increased AIx has been observed in PD patients with comorbid conditions such as metabolic syndrome, the relationship between temporal changes in peritoneal transport characteristics and systemic arterial stiffness remains poorly understood (22,23). There are no studies in the literature investigating the relationship between peritoneal permeability and arterial stiffness indices.

In this study, we aimed to investigate whether longitudinal changes in PET status are associated with alterations in arterial stiffness markers particularly PWV and AIx in a cohort of chronic PD patients.

METHODS

Study Design and Participants

This retrospective observational cohort study included 43 incident adult patients undergoing PD who were followed between 2020 and 2024 at the Peritoneal Dialysis Unit, Department of Nephrology, Dokuz Eylül University Hospital. The inclusion criteria were as follows: age ≥18 years, PD duration of at least 24 months, and the availability of both a baseline and at least two consecutive annual PET results. Patients with active infections, malignancies, recent cardiovascular events, or without a baseline PET were excluded from the study.

Peritoneal Equilibration Test (PET)

PET is a standardized method used to evaluate the permeability of the peritoneal membrane to small solutes. Based on the dialysate/plasma (D/P) creatinine ratio typically measured at the 4th hour patients are classified into four peritoneal transport categories: high (D/P ≥ 0.81), high-average (0.65–0.80), low-average (0.50–0.64), and low transporters (D/P ≤ 0.49). When the PET classification remains unchanged over time, it is defined as "stable PET," while increase or decrease at least one categoric is considered a "PET change."

Grouping According to PET Changes

According to the change in PET classification category, patients were divided into two groups: the "stable PET" group consisting of patients with stable PET categories over time (n=25) and the "changed PET" group consisting of patients with ≥1 category change in PET classification (n=18).

Assessment of Arterial Stiffness

Arterial stiffness parameters were assessed using a validated oscillometric pulse wave analysis device (Mobil-O-Graph; IEM GmbH, Germany). Measurements were performed on the brachial artery under standardized resting conditions. Three consecutive readings were obtained, and the mean values were used in the analysis. PWV was measured to evaluate large artery stiffness, while AIx served as an indicator of small artery stiffness.

Additional Clinical Parameters and Ethical Approval

Additional clinical parameters included blood pressure, ejection fraction, hemogram indices, serum biochemical values, mineral metabolism markers, and peritonitis history. The study was approved by the Non-Interventional Clinical Research Ethics Committee of Dokuz Eylul University Faculty of Medicine and conducted in accordance with the principles outlined in the Declaration of Helsinki. This study was approved by the Non-Interventional Clinical Research Ethics Committee of Dokuz Eylul University Faculty of Medicine (Approval No: 2024/23-05).

STATISTICAL ANALYSIS

Continuous variables were presented as means with standard deviations or as medians with interquartile ranges, depending on their distribution. All clinical and demographic data were retrieved from the hospital's electronic medical record system. Comparisons between groups were performed accordingly. Statistical analyses were conducted using the Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, Version 26.0; IBM Corp., Armonk, NY, USA). Parametric variables were analyzed using the Student's t-test, non-parametric variables using the Mann–Whitney U test, and categorical variables using the chi-square test. A p-value of <0.05 was considered statistically significant.

RESULTS

A total of 43 patients were included in the analysis and categorized into two groups based on temporal changes in their PET classification: the stable PET group (n=25) and the changed PET group (n=18). Baseline

Table 1. Baseline characteristics of study participants

Parameter	Stable PET (n = 25)	Changed PET (n = 18)	p-value
Age (years, mean ± SD)	63.4 ± 13.9	61.6 ± 9.5	0.63
Sex, F/M, n (%)	11 (44%) / 14 (56%)	11 (61.1%) / 7 (38.8%)	0.26
BMI (kg/m², mean ± SD)	27.8 ± 5.0	27.3 ± 4.3	0.81
Diabetes Mellitus, n (%)	8 (32%)	3 (16.6%)	0.25
Hypertension, n (%)	15 (60%)	13 (72.2%)	0.40
Cardiovascular disease, n (%)	4 (16%)	1 (5.5%)	0.29
Baseline PET category, n (%)			0.92
Low	1 (4%)	1 (5.5%)	
Low-average	6 (24%)	3 (16.6%)	
High-average	15 (60%)	11 (61.1%)	
High	3 (12%)	3 (16.6%)	
Dialysis modality (CAPD/APD), n (%)	21 (84%) / 4 (16%)	14 (77.7%) / 4 (22.3%)	0.60
Dialysis duration (months, median, IQR)	36 (12–32)	24 (12–108)	0.28
Ejection fraction (%), mean ± SD	61.2 ± 2.3	60.0 ± 2.0	0.25
Systolic BP (mmHg, mean ± SD)	142.8 ± 15.8	139.8 ± 22.3	0.74
Diastolic BP (mmHg, mean ± SD)	83.5 ± 11.7	86.0 ± 13.8	0.67
Residual renal function (mL/day, median, IQR)	1500 (750–3000)	1400 (0–3000)	0.39
Peritonitis episodes (median, IQR)	1 (0–5)	0.5 (0–7)	0.55

BMI ; Body Mass Index, PET; Peritoneal Equilibration Test, CAPD; Continuous Ambulatory Peritoneal Dialysis, APD; Automated Peritoneal Dialysis, BP; Blood Pressure, SD; Standard Deviation, IQR; Interquartile Range

demographic and clinical characteristics, including age, sex, body mass index (BMI), presence of diabetes or hypertension, cardiovascular disease history, dialysis modality continuous ambulatory peritoneal dialysis (CAPD) vs. automatic peritoneal dialysis (APD), peritonitis frequency, and total dialysis duration, did not significantly differ between the groups (Table 1).

Laboratory parameters such as baseline serum sodium, potassium, albumin, hemoglobin, calcium, phosphorus, bicarbonate, parathyroid hormone levels, and ejection fraction were comparable between the groups. Systolic and diastolic blood pressure values were also similar (Table 2).

Regarding arterial stiffness parameters, mean PWV values were similar between the groups (stable PET: 9.3 ± 2.1 m/s vs. changed PET: 9.3 ± 1.9 m/s; p = 0.90). The mean AIx was significantly higher in the changed PET group compared to the unchanged group (30.6 ± 10.2 vs. 23.0 ± 10.6; p = 0.02) (Table 3).

DISCUSSION

This study examined the relationship between longitudinal changes in peritoneal membrane transport characteristics and arterial stiffness parameters in patients undergoing peritoneal dialysis. Our findings demonstrate that patients who experienced a change in their PET classification exhibited significantly higher AIx values compared to those with stable transport status. In contrast, PWV, which reflects large artery stiffness, did not differ significantly between the groups. These results suggest that dynamic changes in peritoneal transport properties may reflect systemic processes rather than being solely attributable to local peritoneal alterations.

Over time, various factors contribute to alterations in peritoneal membrane permeability. Pathophysiological mechanisms such as the accumulation of AGEs due to prolonged exposure to glucose-based dialysate, chronic

Table 3. Pulse Wave Analysis Results

Parameter	Stable PET (n = 25)	Changed PET (n = 18)	p value
PWV (m/s)	9.3 ± 2.1	9.3 ± 1.9	0.90
AIx (%)	23.0 ± 10.6	30.6 ± 10.2	*0.02*

Table 2. Laboratory Parameters of the Study Population

Parameter	Stable PET (n = 25)	Changed PET (n = 18)	p-value
Sodium (mmol/L)	139.3 ± 3.3	137.2 ± 4.6	0.29
Potassium (mmol/L)	5.0 ± 0.4	5.0 ± 0.6	0.95
Albumin (g/dL)	3.8 ± 0.3	3.5 ± 0.4	0.12
Hemoglobin (g/dL)	10.8 ± 2.1	9.8 ± 1.4	0.25
Calcium (mg/dL)	9.1 ± 0.8	9.1 ± 0.7	0.82
Phosphorus (mmol/L)	5.1 ± 1.7	5.1 ± 1.1	0.99
Alkaline phosphatase (U/L)	83.3 ± 28.0	82.0 ± 29.6	0.92
Bicarbonate (mmol/L)	24.3 ± 2.4	22.6 ± 2.6	0.19
PTH (pg/mL, median, IQR)	255.8 (111.7–710.6)	278.7 (29.9–1005.4)	0.96

PET, peritoneal equilibration test; SD, standard deviation; IQR, interquartile range; PTH, parathyroid hormone.

peritoneal inflammation, neoangiogenesis, vascular sclerosis, peritoneal sclerosis and fibrosis, activation of cytokines including transforming growth factor-beta (TGF-β) and vascular endothelial growth factor (VEGF), as well as peritoneal microcalcification, have all been implicated (24-26). In addition, clinical and treatment-related factors such as a history of peritonitis, long-term peritoneal dialysis (particularly beyond five years), and poor glycaemic control also play a significant role in the progression of membrane alterations. It should be considered whether factors long accepted as local consequences of peritoneal involvement might in fact reflect underlying systemic pathophysiological mechanisms.

The accumulation of advanced glycation end products (AGEs) induces the release of proinflammatory mediators, such as tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6), contributing to systemic inflammation and endothelial dysfunction. A study has shown that longitudinally high levels of high-sensitive C-reactive protein (hs-CRP) is associated to increased peritoneal permeability (27). These results are consistent with the hypothesis that changes in peritoneal permeability may be driven, at least in part, by systemic mechanisms.

Chronic inflammation, glucose-based solutions, hypoxia, and other stimuli increase the expression of angiogenic mediators such as vascular endothelial growth factor (VEGF). VEGF-A increases endothelial cell proliferation and vascular permeability. Angiopoietin and hypoxia-induced factor (HIF-1α) support angiogenesis. As a result, small water-soluble molecules, such as urea, creatinine, and glucose, diffuse more rapidly into the peritoneal cavity. Ultrafiltration is impaired because glucose is rapidly reabsorbed as the osmotic gradient is lost. In one study, higher VEGF levels were detected in patients using solutions containing high glucose, and increased peritoneal permeability was also demonstrated in these patients (24). In another study, increased HIF-1α was associated with pathological changes in permeability (28).

Chronic glucose exposure increases TGF-beta release. Fibroblast activation leads to extracellular matrix accumulation. As a result, submesothelial fibrosis, basal membrane thickening, and capillary wall sclerosis occur. Solute transport becomes irregular, and the transcapillary permeability of the peritoneum increases pathologically. A study has demonstrated a close association between TGF-beta release and peritoneal fibrosis (25,26).

Peritoneal calcification is one of the histomorphological consequences of long-term PD (29). In a study where peritoneal tissue samples were taken, peritoneal microcalcification was observed in 12 of 18 patients who had undergone long-term PD (30). There are limited studies that propose whether peritoneal calcification frequently observed in patients undergoing peritoneal dialysis is a causative factor in peritoneal membrane injury or merely a consequence of ongoing structural damage. However, a study has shown that high Ca×P levels are associated with increased permeability (31).

The strengths of our study include the use of consecutive annual PET assessments, simultaneous measurement of arterial stiffness parameters using a validated device, and long follow-up duration. These features allow for a more robust temporal evaluation of both peritoneal and vascular changes. However, several limitations should be acknowledged. First, the retrospective nature of PET data collection and the relatively small sample size reduce the statistical power and limit the generalizability of our findings. A formal a priori or post hoc power analysis was not feasible due to the retrospective design and limited cohort size; however, the observed effect size for AIx was consistent with previously published data, suggesting that the study was sufficiently sensitive to detect clinically meaningful differences. Second, the absence of direct endothelial or inflammatory biomarkers restricts our ability to validate the proposed mechanistic link between peritoneal transport alterations and vascular stiffness. Since the study was designed retrospectively based on existing clinical and dialysis records, data on circulating inflammatory or endothelial markers (such as hs-CRP, IL-6, or VEGF) were not uniformly available and thus could not be included in the analysis. Future prospective studies incorporating these biomarkers may provide a more comprehensive understanding of the systemic processes contributing to both peritoneal and vascular changes.

CONCLUSION

In conclusion, our findings indicate an associative relationship between longitudinal changes in peritoneal membrane transport characteristics and increased small artery stiffness, as reflected by higher AIx values. No significant difference was observed in PWV, suggesting that large artery stiffness may be less influenced by peritoneal transport dynamics. These results imply that AIx may serve as a sensitive, non-invasive marker for early detection of microvascular alterations in peritoneal dialysis patients. However, the present data do not establish causality, and the observed associations should be interpreted with caution. Future prospective studies with larger sample sizes and biomarker-based endothelial assessments are warranted to clarify the underlying mechanisms and temporal relationships.

DECLARATIONS

Ethics Committee Approval: The study was approved by the Non-Interventional Clinical Research Ethics Committee of Dokuz Eylul University Faculty of Medicine, Izmir, Turkey (Approval No: 2024/23-05). All procedures were conducted in accordance with the ethical standards of the institutional research committee and with the principles outlined in the Declaration of Helsinki.

Data Availability: The datasets generated and analyzed during the current study are available from the corresponding author, Dr. Ilker Atay (email: ilkeratayy@gmail.com), upon reasonable request.

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