MEASURING PERITONEAL ABSORPTION WITH THE PROLONGED PERITONEAL EQUILIBRATION TEST FROM 4 TO 8 HOURS USING VARIOUS GLUCOSE CONCENTRATIONS

Josep Teixidó-Planas,^{1,2} Maria Isabel Troya-Saborido,¹ Guillermo Pedreira-Robles,²
Milagros Del-Rio-Lafuente,¹ Ramon Romero-Gonzalez,¹ and Josep Bonet-Sol¹

*Nephrology Department,¹ Hospital Universitari, and Fundació Institut d'Investigació en Ciències de la Salut,²
Germans Trias i Pujol, Barcelona, Spain*

◆ **Background:** Peritoneal fluid flows such as small-pore ultrafiltration and free water transport can now be calculated by means of the modified peritoneal equilibration test (PET). To calculate peritoneal fluid absorption, volume markers have been used, but that method is not easily applicable in clinical practice. Alternatively, absorption can be estimated using the personal dialysis capacity test. However, a method of measuring overall peritoneal absorption together with the PET is lacking. The aim of the present study was to assess whether overall peritoneal absorption was different when measured from the 4th to 8th hour in a prolonged PET using three different glucose solutions.

◆ **Methods:** The study enrolled 32 stable peritoneal dialysis (PD) patients from a tertiary university hospital, who underwent three 8-hour prolonged PETs with 1.36%, 2.27%, and 3.86% glucose solution. The PETs were performed in random order over a period of less than 1 month. During the prolonged PET, the peritoneal volume was emptied and reinfused at 60 and 240 minutes and drained at 480 minutes. Peritoneal absorption was calculated as the volume difference between the 4th and the 8th hour.

◆ **Results:** The dialysate-to-plasma ratio (D/P) of urea, the D/P creatinine, and the mass transfer area coefficient (MTC) of creatinine at 240 minutes were not significantly different with the three glucose solutions. The end-to-initial (D/D0) glucose, MTC urea, and MTC glucose were significantly different. All water transport parameters were significantly different, except for the 4- to 8-hour absorption volumes and rates. The peritoneal absorption rates were, for 1.36% solution, 1.03 ± 0.58 mL/min [95% confidence interval (CI): 0.83 to 1.24 mL/min]; for 2.27% solution, 0.86 ± 0.71 mL/min (95% CI: 0.61 to 1.11 mL/min); and for 3.86% solution, 1.05 ± 0.78 mL/min (95% CI: 0.77 to 1.33 mL/min). Peritoneal absorption volumes and rates from the 4th to the 8th hour showed good correlations for the various solutions.

◆ **Conclusions:** Using any glucose solution, the prolonged PET with voiding and reinfusion at the 4th hour could be a practical method for calculating overall peritoneal absorption from the 4th to the 8th hour in PD patients.

Perit Dial Int 2014; 34(6):605–611 www.PDIConnect.com
doi: 10.3747/pdi.2013.00235

KEY WORDS: Peritoneal absorption or reabsorption; peritoneal water transport; peritoneal fluid flow pathways; peritoneal function test.

The risk of ultrafiltration failure (UFF) in patients undergoing peritoneal dialysis (PD) can reach 36% after 4 years on PD (1,2), and UFF has been associated with both poor patient and poor technique survival. True UFF is defined by the International Society for Peritoneal Dialysis as ultrafiltration (UF) of less than 400 mL after a 4-hour peritoneal equilibration test (PET) with 3.86% or 4.25% glucose solution (3), which is the most widely used test for the evaluation of peritoneal membrane characteristics (4,5), regardless of the underlying fluid flow mechanisms.

Among the possible causes or mechanisms of UFF, the 4-hour PET can reveal high or low solute transport. Modifications of the PET (5–8) might detect impaired free water transport (aquaporin damage). However, the PET is not a good indicator of high peritoneal absorption of fluid, which might be present in 30%–57% of patients with UFF (1,2,6,9–11), mainly when patients have more than one cause of UFF (1,2,6,9–11).

Peritoneal absorption, reported as lymphatic absorption, has been calculated using macromolecular volume markers such as radioiodinated serum albumin (RISA) (1,9,10,12,13) or dextran 70 (6,14,15), methods that are applicable in only a limited number of PD units.

Using RISA as peritoneal volume marker in a 6-hour PET with 1.36%, 2.27%, or 3.86% glucose solution,

Correspondence to: J. Teixidó-Planas, C/ Quintana Alta 53,
2-A, Badalona 08911 Barcelona, Spain.

jteixido@acmcb.es

Received 1 September 2013; accepted 2 January 2014

Heimbürger *et al.* found—in the third period of the dwell, between the 4th and the 6th hour—net reabsorption at a rate of about 1.0–1.1 mL/min, independent of the initial glucose concentration (13). However, that measurement is not included in the routine 4-hour PET (4,5,16).

Despite the evidence that macromolecular volume markers allow for a calculation of lymphatic absorption (13,15,17), it has been a subject of debate whether clearance of those markers from the peritoneal cavity is indicative of peritoneal absorption or other factors involved in peritoneal fluid flows (9,17–21), and the methods used to measure peritoneal absorption based on volume marker clearance are not conclusive.

Alternatively, the personal (peritoneal) dialysis capacity test (PDC), which is based on three-pore model assumptions and estimations, can be used to obtain peritoneal absorption without using volume markers (4,5,22,23). In a 24-hour period, the patient carries out 5 peritoneal exchanges of different durations using different glucose concentrations; the varying effluent volumes allow for a calculation of peritoneal absorption. This method has been reported to be superior to the PET in terms of discriminating inflammation as a cause of fast transport status (24). However, other authors have suggested that, compared with the PET, the PDC has a number of disadvantages (5).

Recently, Waniewski *et al.* (25) reported peritoneal absorption results for 83 continuous ambulatory PD (CAPD) patients who used 1.36%, 2.27%, and 3.86% glucose on three different days for the overnight exchange (8-hour dwell). Without using peritoneal volume markers or mathematical models, those authors reached results similar to those from Heimbürger *et al.* (13).

Although small-pore UF and free water transport can now be calculated (6,7,26), a method of measuring overall peritoneal absorption together with the PET without the use of volume markers is lacking (4,5,16). The objective of the present study was to assess whether peritoneal absorption is different with the use of three glucose concentrations (1.36%, 2.27%, and 3.86%), when measured from the 4th to the 8th hour; to ensure that the main fluid flow is peritoneal absorption, whatever the underlying mechanism; and to determine if this method combined with the PET could be used to measure overall peritoneal absorption.

METHODS

PATIENTS

Of 48 patients from a tertiary university hospital PD unit proposed for the study, 16 were excluded: 9 patients were too frail, 6 could not participate because of working

or living at a long distance, and 1 did not consent to participate. The final number of participants was therefore 32: 19 men (59%) and 13 women, 54.6 ± 16.4 years of age (range: 24–86 years), with a height of 166.16 ± 6.63 cm (range: 150–179 cm), a weight of 73.3 ± 14.03 kg (range: 44.2–95.0 kg), and no peritonitis during the 2 months preceding the study. The mean duration of PD treatment in this group was 20.44 ± 18.02 months (range: 4–84 months), with 4 patients being treated using incremental dialysis (1 bag at night); 18 patients, with CAPD; and 10 patients, with automated PD.

PROCEDURES

This pilot study was conducted as an observational study with a medical product currently in use (phase IV). The study complies with the Declaration of Helsinki principles and was approved by the local ethics committee. Each patient provided written informed consent.

Each patient underwent three prolonged 8-hour PETs using 1.36%, 2.27%, and 3.86% glucose solution (to calculate solute and fluid transport) and 1 PDC test (to obtain the area parameter and peritoneal absorption), which were performed in random order over a period of less than 1 month. The solutions used were low in glucose degradation products.

8-Hour Prolonged PET: The night before the test, patients performed a manual exchange with 2 L of 2.27% glucose, which was drained in the hospital. The 8-hour prolonged PET was carried out with temporary drainage—the drain bag being weighed and reinfused—at 60 and 240 minutes (8). After the 4th-hour reinfusion, patients were allowed to leave the hospital and to have a meal with a maximum water intake of 200–300 mL. Patients were allowed to take upright and seated positions, but not a recumbent position. The final drain was carried out in the hospital 4 hours later (8th hour of the PET).

A blood sample was drawn at 240 minutes, and dialysate samples (10 mL each) were taken from the effluent of the night bag before the test infusion and at 0, 60, 120, 240, and 480 minutes of the test dwell. The analyses included urea, creatinine, glucose, sodium, and potassium. A correction for plasma water concentration was applied for small solutes in blood. The dialysate creatinine concentration was corrected for the presence of glucose.

CALCULATIONS

At 240 minutes, the dialysate-to-plasma ratios for urea and creatinine were obtained, as was the end-to-initial dialysate ratio (D/D_0) for glucose; at the same time,

the mass transfer area coefficients (MTCs), corrected for 1.73 m² body surface area, were calculated for urea, creatinine, and glucose (27). Peritoneal residual volume was calculated at the start of the test bag using the means of urea and creatinine, with the assumption that the residual volume was equal at 60, 240, and 480 minutes. Small-pore UF and free water transport were estimated (7). The dialysate osmolality was calculated as 2 Na + Glucose + Urea (in millimoles per liter). The peritoneal absorption volume was the difference between the 4-hour and the 8-hour effluent volumes. The absorption rate was the 4- to 8-hour absorption volume, divided by the minutes elapsed between those two effluent volume determinations.

The PDC test (Synergy 3.0: Gambro Lundia, Lund, Sweden) was carried out using a combination of solutions: 2 bags 1.36% glucose and 3 bags 2.27% glucose. The area parameter and the PDC peritoneal absorption rates were included in the database.

STATISTICAL ANALYSIS

Data are presented as mean $\pm$ standard deviation, with a minimum-to-maximum range or 95% confidence interval (CI). The variables of interest were normally distributed (Kolmogorov–Smirnov test). Data were analyzed using single-factor analysis of variance and the Bonferroni *post hoc* test, the Student *t*-test, and Spearman correlations (SPSS, version 15.0: SPSS, Chicago, IL, USA). Statistical significance was defined as $p < 0.05$.

RESULTS

The solute transport parameters at 240 minutes of the prolonged PET were not significantly different with the three glucose concentrations, except for D/D₀ glucose, MTC urea, and MTC glucose (Table 1).

The dialysate glucose concentration was significantly different at all time points. The calculated osmolality was significantly different at 60 and 240 minutes, but not at 240 minutes for the 1.36% and 2.27% solutions in the *post hoc* analysis. No differences were found at 480 minutes (Table 1).

Water transport parameters were significantly different for the three glucose concentrations, except for the volume and rate of peritoneal absorption (Table 1). The mean absorption volume was 255.91 ± 177.20 mL (95% CI: 220 to 292 mL) for the three solutions, and the mean absorption rate was 0.98 ± 0.69 mL/min (95% CI: 0.84 to 1.12 mL/min; Figure 1).

Significant pairwise correlations were found for the peritoneal absorption rate: 1.36% versus 2.27%

glucose: $r = 0.513$, $p = 0.003$; 1.36% versus 3.86% glucose: $r = 0.587$, $p < 0.001$; and 2.27% versus 3.86% glucose: $r = 0.606$, $p < 0.001$.

Taken together, the 4- to 8-hour absorption rates for three solutions showed good correlation with the solute transport parameters and an inverse correlation with net UF at 240 minutes and especially at 480 minutes (Table 2).

The peritoneal absorption rate calculated from the PDC (1.83 ± 0.63 mL/min/1.73 m²) was significantly greater than the prolonged PET peritoneal absorption rate (0.94 ± 0.65 mL/min/1.73 m², $p < 0.001$) and maintained a weak correlation ($r = 0.384$, $p < 0.001$). The area parameter calculated from the PDC ($21\,577 \pm 11\,146$ cm; 95% CI: 17\,559 to 25\,596 cm) correlated with the small-solute MTCs: urea ($r = 0.561$), creatinine ($r = 0.713$), and glucose ($r = 0.592$)—all $p < 0.001$.

DISCUSSION

Data from this pilot study show that the overall peritoneal absorption volumes and rates from 4 to 8 hours are not significantly different with 1.36%, 2.27%, and 3.86% glucose solutions. If these results are confirmed by other studies, this method could provide an assessment of individual overall peritoneal absorption, without the need for volume markers or theoretical assumptions, and could detect patients whose UFF results from high peritoneal absorption. In addition, the effluent volumes allow an 8-hour peritoneal volume–time curve to be drawn, which could be useful for a comprehensive understanding of the relative contributions of small-pore and free water transport to total fluid flows.

In this study, peritoneal absorption was calculated during the third period of the PET, when fluid absorption predominates over other fluid flows in most patients. Depending on transport status, and especially on the concentration of glucose used as the osmotic agent, the decline in volume might start at a different time point during the peritoneal dwell. In the study by Heimbürger *et al.* of 33 CAPD patients undergoing a 6-hour PET using RISA and 1.36% ($n = 9$), 2.27% ($n = 9$), or 3.86% glucose ($n = 23$), the period between the 4th and the 6th hour showed net absorption at the same rate for all three glucose concentrations (13). However, some patients with low solute transport or a high UF rate (or both) might maintain positive UF beyond the 4th hour of the dwell. Because of that possibility, it would be more accurate to measure peritoneal absorption from the 6th to the 8th hour. In our study, we chose to measure peritoneal absorption from the 4th to the 8th hour so as to combine that measurement with the 4-hour PET and to increase the probability that most of the patients would

TABLE 1
Solute and Water Transport with 1.36%, 2.27%, and 3.86% Glucose Peritoneal Dialysis Solutions^a

Variable	Glucose concentration of the study solution			<i>p</i> Value
	1.36%	2.27%	3.86%	
Solute transport (240 minutes)				
D/P urea	0.83±0.06	0.84±0.06	0.85±0.05	NS
D/P creatinine	0.64±0.11	0.65±0.11	0.67±0.11	NS
D/D ₀ glucose	0.45±0.10	0.37±0.09	0.29±0.07	<0.001
MTC urea	16.17±3.56	17.12±4.06	19.37±4.58	<0.01
MTC creatinine	9.55±3.87	9.80±3.49	11.12±4.27	NS
MTC glucose	9.00±2.75	10.34±3.00	13.62±3.41	<0.001
Dialysate glucose and osmolality (mmol/L)				
60 Minutes				
Glucose	51.47±5.54	76.53±8.16	113.18±12.93	<0.001
Omolality ^b	325.00±5.30	343.86±7.31	375.02±10.73	<0.001
240 Minutes				
Glucose	31.77±6.79	42.83±11.20	56.05±13.91	<0.001
Osmolality ^b	317.12±7.18 ^c	321.27±9.73 ^c	329.21±10.59	<0.001
480 Minutes				
Glucose	17.83±6.70	23.53±8.72	27.14±10.39	<0.001
Omolality ^b	312.38±7.93	314.32±8.06	314.47±10.09	NS
Water transport				
Ultrafiltration (mL)				
60 Minutes	41.09±156	153.38±108	418.88±163	<0.001
240 Minutes	−61.38±210	169.88±181	586.34±202	<0.001
480 Minutes	−326.16±281	−55.78±335	308.94±345	<0.001
Reabsorption, 4-hour to 8-hour				
Milliliters	264.78±142	225.53±185	277.41±201	NS
(95% confidence interval)	213.58 to 315.98	158.89 to 292.17	204.94 to 349.87	
Milliliters per minute	1.03±0.58	0.86±0.71	1.05±0.78	NS
(95% confidence interval)	0.83–1.24	0.61–1.11	0.77–1.33	

D/P = dialysate-to-plasma ratio; NS = nonsignificant; D/D₀ = end-to initial dialysate ratio; MTC = mass transfer area coefficient (mL/min/1.73 m²).

^a Results presented as mean ± standard deviation.

^b Calculated as: 2 Na (mmol/L) + Glucose (mmol/L) + Urea (mmol/L)

^c By Bonferroni post-hoc test.

be in the absorption period. During the study, the patients returned to the hospital for the final peritoneal drain and measurements of the time and the effluent volume. However, in clinical practice, those measurements can be obtained at home.

Some concerns require consideration. First, the calculated osmolality for 3.86% glucose at 240 minutes was significantly higher than that for 1.36% or 2.27% glucose, suggesting that positive transcapillary UF might still be acting beyond 240 minutes. However, compared with the lower-osmolality solutions (1.36% and 2.27% glucose), the 3.86% glucose solution did not show a trend toward decreased absorption volume or rate, as would be expected to accompany the higher osmolality, nor a

trend toward increased absorption because of a higher intraperitoneal volume or pressure.

Second, bivariate correlations for the absorption volumes and rates with the three glucose concentrations were only good or acceptable. Substantial variability has been reported for solute and water transport rates in individual patients (28). The classic PET shows a 2%–20% variability coefficient for the transfer of low molecular weight solutes (29) and a 7%–30% variability in UF (29). Moreover, in our study, the residual volume was calculated only at the start of the dwell. Those factors account for some variability in the results.

Third, the sample size was limited. The power analysis based on our data pointed to a need to enroll 215 patients

Figure 1 — Peritoneal absorption rates from 4 hours to 8 hours, presented as negative ultrafiltration. The boxes indicate the 95% confidence intervals, and the lines indicate the minimum and maximum values. The 95% confidence interval for the three glucose solutions combined was 0.84 – 1.12 mL/min.

to find significant differences with a single-factor analysis of variance ($\alpha = 0.05$ and $\beta = 0.80$). However, for a pilot study, we believe that our 32 patients were sufficient as a first step in testing this approach. Whether the difference in the calculated osmolality for a 3.86% glucose solution at 240 minutes might result in differences in the 4- to 8-hour absorption requires further investigation with a more extensive sample.

The correlations between the 4- and 8-hour peritoneal absorption measurements and the solute transport parameters were stronger than those with peritoneal UF (Table 2). That finding accords with results of previous studies on peritoneal absorption, which suggested that back-filtration is the main component of absorption (9,30–32); for other authors, lymphatic uptake prevailed (2,14,17). However, the relationship between peritoneal absorption and small-solute transport was not found in other studies (25,33,34).

In our study, the PDC absorption parameter was significantly higher than the absorption calculated from the prolonged PET, but the latter number accords with results in other published studies. Fluid absorption in the PDC was 1.97 ± 1.0 mL/min/ 1.73 m² in a multicenter study of 336 patients (23), and 2.03 ± 1.04 mL/min/ 1.73 m² for patients less than 65 years of age and 1.92 ± 1.14 mL/min/ 1.73 m² for patients more than 65 years of age in another study (35). Those figures are very close to our PDC results. However, the PDC absorption results do not agree with lymphatic absorption studies (2,6,9,14,15) or with simulations in the three-pore model, in which net

TABLE 2
Correlations for Peritoneal Reabsorption Rate with Solute Transport and Ultrafiltration (UF) in the Prolonged Peritoneal Equilibration Test

Variable	4-Hour to 8-hour reabsorption rate (milliliters per minute)	
	R	p Value
MTC urea ^a	0.415	0.000
MTC creatinine ^a	0.647	0.000
MTC glucose ^a	0.512	0.000
Net UF at 240 minutes	-0.255	0.012
Net UF at 480 minutes	-0.564	<0.001

MTC = mass transfer area coefficient.

^a Calculated at 240 minutes.

fluid loss from the peritoneal cavity is the sum of lymphatic absorption (0.2 – 0.3 mL/min) and back-filtration through the capillary small pores (~0.9 mL/min), accounting for approximately 1.2 mL/min (19,36,37), results that resemble our prolonged PET absorption results.

The reason for the wide gap between the PDC absorption parameter and the peritoneal absorption determined using our method or found in other studies that reached similar results (13,25) is unclear. Van Biesen *et al.* (23) found this difference and asserted that the final part of the curve of the PDC peritoneal volume depended strongly on the volume drained after the long overnight dwell. If that drain is incomplete, the PDC reabsorption will be overestimated. Because that parameter is not needed for the calculations of other parameters, it can be seen as a peculiarity of the program without further importance (23). From our point of view, PDC calculates fluid flows based on the transcapillary transport formulas of the three-pore model, which account for all absorption flows as lymphatic and capillary back-filtration (5,22), but—it could perhaps be speculated—might not correctly account for capillary positive UF, which in part counteracts fluid absorption. On the other hand, our peritoneal absorption refers to the phenomenon of declining peritoneal volume regardless of the fluid flow mechanisms involved, and does not depend on mathematical models. Thus, in our opinion, the PDC and the 4- to 8-hour absorption are measuring different phenomena at different levels that deserve further investigation.

For many years, peritoneal absorption has been reported as lymphatic absorption obtained with the use of intraperitoneally administered macromolecular volume markers. The use of macromolecular markers in PD is based on dilution measures to calculate the peritoneal volume and on the clearance rate of the

marker to estimate the lymphatic absorption of fluid, by both subdiaphragmatic and interstitial lymphatics, using K_E term as a correction factor (1,10,12,13) or not (2,6,14,17). The finding that the fluid absorption rate from the 4th to the 6th hour and the clearance rate of the marker, RISA, were similar, with a positive correlation, suggests that K_E and the fluid absorption rate reflect lymphatic absorption (13). However, only about 20% of the clearance rate of the marker was recovered in circulating blood (20). A large number of studies have therefore focused on the disappearance of the marker. Despite some evidence in favor of the disappearance (or clearance) of a macromolecular marker from the peritoneal cavity as an indirect measure of lymphatic absorption (9,15,17), that disappearance might overestimate the overall net peritoneal absorption (10,19,20,36) despite the use of the K_E term as a correction factor. Moreover, fluid loss from the peritoneal cavity by the lymphatics that open directly to the cavity is about 5% – 25%; the rest is absorbed into the tissue surrounding the cavity (38). The fluid that enters the tissue might be absorbed into the interstitial lymphatics or into the blood capillaries in a proportion that is difficult to ascertain, a subject that has been controversial (17,18,19,21).

Stachowska-Pietka *et al.* (30) applied the distributed model to peritoneal fluid absorption, using a mathematical model to simulate the process of water reabsorption, assuming that the infused fluid was isotonic. They predicted that, in the steady state, approximately 20% – 40% of the fluid that flows into the tissue of the peritoneal cavity is absorbed by interstitial lymphatics, and that approximately 60% – 80% of the fluid is absorbed by blood capillaries. Asghar and Davies, in a study of two 6-hour PETs with 1.36% and 3.86% glucose using RISA as volume marker, found a proportional relationship between peritoneal fluid absorption and small-solute transport that was more apparent with 1.36% than with 3.86% glucose solution (31), reinforcing the idea that direct lymphatic absorption makes up a relatively minor proportion of fluid absorption in PD (9,30,39).

Thus, whether peritoneal absorption depends mainly on lymphatic or capillary absorption (back-filtration), or on the trapping of molecules in tissue, has remained controversial (9,17–19,21,36), and the methods used to calculate peritoneal absorption with volume markers have not been conclusive.

Recently, Waniewski *et al.* (25) reported results for 83 CAPD patients who used 1.36%, 2.27%, and 3.86% glucose for the overnight exchange (8-hour dwell) on three different days. Their estimated peritoneal absorption was 0.94 ± 0.92 mL/min, results that are very similar to our peritoneal absorption data.

CONCLUSIONS

Over the years, peritoneal absorption has been calculated as lymphatic absorption using macromolecular volume markers (6,9,14,15,31), which presents some methodologic concerns and might overestimate overall peritoneal absorption (10,19,20,36,37). If the method described in the present study is confirmed, the use of any glucose concentration might be able to measure, without volume markers, the various fractional flow pathways and overall peritoneal absorption, and could be useful and applicable in almost all PD units.

ACKNOWLEDGMENTS

We are grateful to Drs. Maria Doladé and Maria Cruz Pastor for the peritoneal sampling process and analysis.

DISCLOSURES

JTP has received research support from Baxter S.L.

REFERENCES

1. Heimbürger O, Waniewski J, Werynski A, Tranæus A, Lindholm B. Peritoneal transport in CAPD patients with permanent loss of ultrafiltration capacity. *Kidney Int* 1990; 38:495–506.
2. Smit W, Schouten N, van den Berg N, Langedijk MJ, Struijk DG, Krediet RT on behalf of the Netherlands Ultrafiltration Failure Study Group. Analysis of the prevalence and causes of ultrafiltration failure during long-term peritoneal dialysis: a cross-sectional study. *Perit Dial Int* 2004; 24:562–70.
3. Mujais S, Nolph K, Gokal R, Blake P, Burkart J, Coles G, *et al.* Evaluation and management of ultrafiltration problems in peritoneal dialysis. International Society for Peritoneal Dialysis Ad Hoc Committee on Ultrafiltration Management in Peritoneal Dialysis. *Perit Dial Int* 2000; 20(Suppl 4):S5–21.
4. van Biesen W, Heimbürger O, Krediet R, Rippe B, La Milia V, Covic A, *et al.* ERBP Working Group on Peritoneal Dialysis. Evaluation of peritoneal membrane characteristics: clinical advice for prescription management by the ERBP Working Group. *Nephrol Dial Transplant* 2010; 25:2052–62.
5. Krediet RT, Struijk DG. Peritoneal dialysis membrane evaluation in clinical practice. *Contrib Nephrol* 2012; 178:232–7.
6. Smit W, van Dijk P, Langedijk MJ, Schouten N, van den Berg N, Struijk DG, *et al.* Peritoneal function and assessment of reference values using a 3.86% glucose solution. *Perit Dial Int* 2003; 23:440–9.
7. La Milia V, Di Filippo S, Crepaldi M, Del Vecchio L, Dell'Oro C, Andrulli S, *et al.* Mini-peritoneal equilibration test: a simple and fast method to assess free water and small

- solute transport across the peritoneal membrane. *Kidney Int* 2005; 68:840–6.
8. Cnossen TT, Smit W, Konings CJ, Kooman JP, Leunissen KM, Krediet RT. Quantification of free water transport during the peritoneal equilibration test. *Perit Dial Int* 2009; 29:523–7.
 9. Heimbürger O, Waniewski J, Werynski A, Park MS, Lindholm B. Lymphatic absorption in CAPD patients with loss of ultrafiltration capacity. *Blood Purif* 1995; 13:327–39.
 10. Waniewski J, Heimbürger O, Park MS, Werynski A, Lindholm B. Methods for estimation of peritoneal dialysate volume and reabsorption rate using macromolecular markers. *Perit Dial Int* 1994; 14:8–16.
 11. Waniewski J, Debowska M, Lindholm B. Water and solute transport through different types of pores in peritoneal membrane in CAPD patients with ultrafiltration failure. *Perit Dial Int* 2009; 29:664–9.
 12. Lindholm B, Heimbürger O, Waniewski J, Werynski A, Bergström J. Peritoneal ultrafiltration and fluid reabsorption during peritoneal dialysis. *Nephrol Dial Transplant* 1989; 4:805–13.
 13. Heimbürger O, Waniewski J, Werynski A, Lindholm B. A quantitative description of solute and fluid transport during peritoneal dialysis. *Kidney Int* 1992; 41:1320–32.
 14. Struijk DG, Krediet RT, Imholz AL, Koomen GC, Arisz L. Fluid kinetics in CAPD patients during dialysis with a bicarbonate-based hypoosmolar solution. *Blood Purif* 1996; 14:217–26.
 15. Struijk DG, Koomen GC, Krediet RT, Arisz L. Indirect measurement of lymphatic absorption in CAPD patients is not influenced by trapping. *Kidney Int* 1992; 41:1668–75.
 16. La Milia V. Peritoneal transport testing. *J Nephrol* 2010; 23:633–47.
 17. Krediet RT. The effective lymphatic absorption rate is an accurate and useful concept in the physiology of peritoneal dialysis. *Perit Dial Int* 2004; 24:309–13.
 18. Flessner M. Effective lymphatic absorption rate is not a useful or accurate term to use in the physiology of peritoneal dialysis. *Perit Dial Int* 2004; 24:313–16.
 19. Rippe B. Free water transport, small pore transport and the osmotic pressure gradient three-pore model of peritoneal transport. *Nephrol Dial Transplant* 2008; 23:2147–53.
 20. Zakaria el R, Mays CJ, Matheson PJ, Hurt RT, Garrison RN. Plasma appearance rate of intraperitoneal macromolecular tracer underestimates peritoneal lymph flow. *Adv Perit Dial* 2008; 24:16–21.
 21. Flessner MF. Distributed model of peritoneal transport: implications of the endothelial glycocalyx. *Nephrol Dial Transplant* 2008; 23:2142–6.
 22. Haraldsson B. Assessing the peritoneal dialysis capacities of individual patients. *Kidney Int* 1995; 47:1187–98.
 23. Van Biesen W, Carlsson O, Bergia R, Brauner M, Christensson A, Genestier S, et al. Personal dialysis capacity (PDC) test: a multicentre clinical study. *Nephrol Dial Transplant* 2003; 18:788–96.
 24. Van Biesen W, Van der Tol A, Veys N, Dequidt C, Vijt D, Lameire N, et al. The personal dialysis capacity test is superior to the peritoneal equilibration test to discriminate inflammation as the cause of fast transport status in peritoneal dialysis patients. *Clin J Am Soc Nephrol* 2006; 1:269–74.
 25. Waniewski J, Paniagua R, Stachowska-Pietka J, Ventura MD, Avila-Diaz M, Prado-Urbe C, et al. Threefold peritoneal test of osmotic conductance, ultrafiltration efficiency, and fluid absorption. *Perit Dial Int* 2013; 33:419–25.
 26. Smit W, Struijk DG, Ho-dac-Pannekeet MM, Krediet RT. Quantification of free water transport in peritoneal dialysis. *Kidney Int* 2004; 66:849–54.
 27. Waniewski J, Werynski A, Heimbürger O, Lindholm B. Simple models for description of small-solute transport in peritoneal dialysis. *Blood Purif* 1991; 9:129–41.
 28. Davies SJ. Mitigating peritoneal membrane characteristics in modern peritoneal dialysis therapy. *Kidney Int Suppl* 2006; (103):S76–83.
 29. Imholz AL, Koomen GC, Voorn WJ, Struijk DG, Arisz L, Krediet RT. Day-to-day variability of fluid and solute transport in upright and recumbent positions during CAPD. *Nephrol Dial Transplant* 1998; 13:146–53.
 30. Stachowska-Pietka J, Waniewski J, Flessner MF, Lindholm B. Distributed model of peritoneal fluid absorption. *Am J Physiol Heart Circ Physiol* 2006; 291:H1862–74.
 31. Asghar RB, Davies SJ. Pathways of fluid transport and reabsorption across the peritoneal membrane. *Kidney Int* 2008; 73:1048–53.
 32. Michels WM, Zweers MM, Smit W, Korevaar J, Struijk DG, van Westrhenen R, et al. Does lymphatic absorption change with the duration of peritoneal dialysis? *Perit Dial Int* 2004; 24:347–52.
 33. Sobiecka D, Waniewski J, Werynski A, Lindholm B. Peritoneal fluid transport in CAPD patients with different transport rates of small solutes. *Perit Dial Int* 2004; 24:240–51.
 34. Galach M, Antosiewicz S, Baczynski D, Wankowicz Z, Waniewski J. Sequential peritoneal equilibration test: a new method for assessment and modelling of peritoneal transport. *Nephrol Dial Transplant* 2013; 28:447–54.
 35. Johansson AC, Haraldsson B. Physiological properties of the peritoneum in an adult peritoneal dialysis population over a three-year period. *Perit Dial Int* 2006; 26:482–9.
 36. Rippe B, Venturoli D. Fluid loss from the peritoneal cavity by back-filtration through the small pores of the three-pore model. *Kidney Int* 2008; 73:985–6.
 37. Rippe B, Venturoli D, Simonsen O, de Arteaga J. Fluid and electrolyte transport across the peritoneal membrane during CAPD according to the three-pore model. *Perit Dial Int* 2004; 24:10–27.
 38. Flessner MF. Net ultrafiltration in peritoneal dialysis: role of direct fluid absorption into peritoneal tissue. *Blood Purif* 1992; 10:136–47.
 39. Waniewski J, Heimbürger O, Werynski A, Lindholm B. Osmotic conductance of the peritoneum in CAPD patients with permanent loss of ultrafiltration capacity. *Perit Dial Int* 1996; 16:488–96.