Determination of Peritoneal Transport Characteristics With 24-Hour Dialysate Collections: Dialysis Adequacy and Transport Test

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(J. Am. Soc. Nephrol. 1994; 5:1333–1338)

ABSTRACT
Although the 24-hour collection of dialysate provides a very accurate measure of the adequacy of dialysis, it is not known if it can also determine peritoneal membrane transport characteristics. In this prospective study, 101 24-hour dialysate collections were immediately followed by a standard peritoneal equilibration test (PET). Four- and 24-h dialysate-to-plasma (D/P) ratios were determined for creatinine and urea. The correlation coefficients between these two tests were 0.86 for the adjusted D/P creatinine and 0.71 for the D/P urea, whereas the standard errors of estimate were 0.054 and 0.060, respectively. Patients were classified into one of four transport groups on the basis of the mean and standard deviation of the adjusted D/P creatinine values, and these values were similar to those generated from the PET data. Rates of ultrafiltration were also defined for patients undergoing 2,0- and 2.5-L dwell. A survey of a subset of these patients demonstrated that the 24-h collection was preferred to the PET for determining transport characteristics. Therefore, the 24-h dialysate collection can be used to monitor both peritoneal membrane transport characteristics and adequacy. This technique, which has been named the "dialysis adequacy and transport test," has the potential for significant cost savings when it is used for the routine follow-up of both peritoneal transport and adequacy of dialysis.

Key Words: Continuous ambulatory peritoneal dialysis, peritoneal equilibration test, dialysis adequacy, peritoneal solute clearance

The formulation of an appropriate dialysis prescription for patients on continuous ambulatory peritoneal dialysis (CAPD) requires knowledge about both peritoneal membrane transport characteristics and solute clearance measured over a 24-h period (1). The peritoneal equilibration test (PET) has gained widespread applicability in assessing the characteristics of peritoneal membrane transport (1). The results from this test have been used to determine the best peritoneal dialysis modality for a particular patient and to document both changes in the peritoneal membrane over time or noncompliance with the dialysis prescription (2,3). However, the standard PET requires approximately 5 h to complete and consumes both nursing time to administer the test as well as dialysate supplies to perform the test. In addition, estimates of 24-h solute clearance based on PET data can be highly variable in individual patients. We have previously demonstrated that clearance estimates based entirely on 4-h PET data can vary by more than 10% from measured 24-h clearance data in more than 50% of CAPD patients (4). Therefore, the gold standard for the determination of solute clearance and 24-h drain volume remains the collection and analysis of dialysate obtained over a 24-h period.

For the clinical nephrologist, the use of one test that would very accurately determine solute clearance but still provide useful, practical clinical information on transport characteristics would provide the information needed to monitor dialysis prescriptions as well as result in a more cost-effective use of health care personnel and supplies. Several preliminary studies suggest that the 24-h dialysate collection would meet these requirements. Wolf et al. (5) studied five CAPD patients and documented a correlation between the dialysate-to-plasma (D/P) ratios from the PET and the D/P ratios from the 24-h dialysate for creatinine and urea. Soon thereafter, Busch et al. (6) demonstrated that serial 24-h D/P ratios for creatinine could be used to determine changes in peritoneal transport in an individual patient. Although limited information is available regarding average 24-h D/P creatinine values and dialysis drain volumes in each of the four PET transport categories (7), we are unaware of published studies in a large group of CAPD patients that rigorously compare transport characteristics obtained from the 24-h dialysate collection and the PET. In this study, we evaluate the use of the 24-h dialysate collection to determine transport characteristics as well as the patient acceptability of this test. This dual use of the 24-h dialysate collection has been named the "dialysate adequacy and transport test" or "DAATT."
METHODS

Subjects

Seventy-five chronic CAPD patients underwent 101 simultaneous PET and 24-h dialysate collections between October 1992 and August 1993. All patients were receiving CAPD with four exchanges of 1.5, 2.0, 2.5, or 3.0 L/day. There were 45 men and 30 women with a mean age (± standard deviation) of 48.4 ± 19.0 yr (range, 18 to 80 yr), of which 67.1% were white and the remainder were African-American.

Twenty-Four-Hour Dialysate Collection

One group of patients (protocol patients) volunteered to follow a standardized protocol during the collection of the 24-h dialysate. This protocol consisted of three exchanges of 5 h each with 1.5% Dianel (Baxter Healthcare Inc., Deerfield, IL) and one overnight exchange of 9 hours with 2.5% Dianel, with each exchange using the patient’s usual dwell volume. A second group of patients declined to follow this protocol (nonprotocol patients), and all dialysate drained from four consecutive dwells over a 24-h period was collected. The patient followed his or her usual dialysis prescription, including dwell times and dwell volumes, during this 24-h collection. For both groups of patients, the dialysate from the four drain bags was combined and then mixed well. The total volume of the dialysate was recorded, and a 10-mL sample was then sent for appropriate laboratory tests. Twenty-four-hour D/P ratios for urea and creatinine were calculated in a standard fashion.

Peritoneal Equilibration Test

Each subject underwent a standard PET immediately after the 24-h dialysate collection was completed. The PET was performed in the usual manner (2), except that the patients used their standard dwell volumes for both studies. No patient had an episode of peritonitis within 1 month of testing.

Laboratory Methods

Dialysate and serum creatinine were measured by standard automated methods by a kinetic modification of the Jaffe procedure (8). Dialysate and serum creatinine were corrected for high glucose concentrations by standard methods (9). Dialysate and serum glucose were measured by a modification of the hexokinase glucose-6-phosphate dehydrogenase (G-6-PD) method (10).

Patient Survey

Thirty-two of the patients participating in the study who had undergone a standard PET, a fast PET (11) and a nonprotocol 24-h dialysate collection were administered a standardized survey. We chose to survey only those CAPD patients at our center who had undergone both the standard and fast PET in order to determine if the fast PET was preferred to the standard PET by our patients. The survey was designed to comparatively assess the patient’s discomfort and inconvenience from the standard PET and the 24-h dialysate collection. The specific factors queried were assessed on a standardized scale from 1 to 6, with 1 indicating very severe, 2 indicating moderately severe, 3 meaning moderate, 4 indicating mild, 5 meaning minimal, and 6 indicating not present. In addition, the technique best preferred by the patient and the reasons for his or her preference were also ascertained. The survey was administered to all patients by the same individual, a peritoneal dialysis nurse.

Statistical Analysis

All data were analyzed with Microsoft Excel 4.0 (Redmond, WA). Calculation of means, standard deviations, paired t tests, correlation coefficients, and regression analyses, including the standard errors of estimate, were performed with this program with standard statistical equations. The exact randomization and χ² tests were performed with True Epistat (Richardson, TX).

RESULTS

Correlation of Four-Hour With Twenty-Four-Hour Transport Results

Thirty-eight tests were completed by use of the standardized 24-h collection protocol, whereas 63 tests were completed without following the protocol. In both groups, the mean D/P creatinine value for the 24-h collection was 0.05 points higher than that for the 4-h D/P creatinine value derived from the PET. Unlike Busch et al., we did not observe that the difference between the 24-h D/P creatinine and the PET D/P creatinine varied among low versus high transporters. The higher value for D/P creatinine seen with the 24-h collection is mostly likely attributable to the longer dwell times associated with the 24-h collection and the corresponding increase in dialysate creatinine. For analysis purposes, we have therefore corrected the 24-h D/P creatinine values to adjust for the relatively longer dwells used with the 24-h collection. The adjusted 24-h D/P creatinine values are obtained by subtracting 0.05 from the actual 24-h D/P creatinine values. These adjusted D/P creatinine values are used in the analyses presented below. Note that the values for 24-h D/P urea did not require this adjustment.

The correlation coefficient between the 4- and 24-h D/P creatinine was 0.83 in the protocol patients and 0.87 in the nonprotocol patients. The correlation coefficient between the 4- and 24-h D/P urea was 0.73 in the protocol patients and 0.70 in the nonprotocol patients. Because the correlation coefficients were similar in the two patient groups, the data from both groups are combined and are depicted in Figures 1 and 2. The overall correlation coefficient for D/P creatinine was 0.86, and for D/P urea, it was 0.71, with a standard error of estimate of 0.054 and 0.060, respectively. By use of the paired t test, there was no significant difference between D/P values calculated from the PET versus those values calculated from the 24-h dialysate (P > 0.05) for either creatinine or urea.

Other Correlations

There were 52 patients who routinely underwent 2-L dwell volumes and 38 patients who used 2.5-L dwell volumes. The correlation coefficients between
Categorization of Transport Groups

We used the method of Twardowski et al. to categorize patients on the basis of their transport characteristics (2). Briefly, this involves determining the mean and standard deviation for D/P ratios and drain volumes in a large number of patients and using these standard deviation values as cutpoints for defining the four transport groups. Table 1 compares the cutpoints reported by Twardowski et al. with the cutpoints we developed for our patient population for both the PET and the 24-h dialysate collection. For the creatinine ratios, there was a very close correlation between the cutpoints reported by Twardowski et al. and our data. Similar findings were evident when D/P urea values were compared (12). Because PET drain volumes are not directly comparable to the 24-h dialysate volume (4), we instead have developed mean and standard deviation values for 24-h dialysate volumes for patients using 2.0- or 2.5-L dwells. These values are reported in Table 2.

Sequential Measures of Twenty-Four-Hour Transport

Twenty-two patients underwent two simultaneous determinations of PET and 24-h dialysate collections that were an average of 181 days apart (standard deviation, 44 days; range, 86 to 278 days). The same dwell volumes were used for both testing periods. The initial D/P creatinine value was 0.62 ± 0.11 from the PET and 0.61 ± 0.10 from the DATT, whereas the final D/P creatinine was 0.63 ± 0.11 from the PET and 0.60 ± 0.08 from the DATT. For urea, the initial D/P value

| Table 1. Comparison of PET with 24-h dialysate transport characteristics |
|---------------------------|-----------------|-----------------|------------------|
|                          | Twardowski et al. (2, 12) | Rocco et al. (this report) | Rocco et al. (this report) |
| D/P Creatinine           |                  |                  |                  |
| Mean + 2 SD              | 0.96             | 0.85             | 0.84             |
| Mean + 1 SD              | 0.81             | 0.75             | 0.74             |
| Mean                    | 0.65             | 0.64             | 0.64             |
| Mean - 1 SD              | 0.50             | 0.54             | 0.54             |
| Mean - 2 SD              | 0.35             | 0.44             | 0.44             |
| Mean - 3 SD              | 0.21             | 0.30             |                  |
| D/P Urea                 | 0.73             | 0.79             | 0.79             |
| Mean + 2 SD              | N/A              | 0.99             | 1.02             |
| Mean + 1 SD              | 0.98             | 0.92             | 0.94             |
| Mean                    | 0.91             | 0.85             | 0.86             |
| Mean - 1 SD              | 0.84             | 0.77             | 0.79             |
| Mean - 2 SD              | N/A              | 0.70             | 0.71             |
| Mean - 3 SD              |                  |                  |                  |
| D/Do Glucose             |                 |                  |                  |
| Mean + 2 SD              | 0.60             | 0.58             | 0.71             |
| Mean + 1 SD              | 0.49             | 0.50             | 0.60             |
| Mean                    | 0.38             | 0.42             | 0.48             |
| Mean - 1 SD              | 0.26             | 0.34             | 0.36             |
| Mean - 2 SD              | 0.15             | 0.26             | 0.24             |

N/A, not available.

the PET and the 24-h D/P creatinine were 0.83 in the 2.0-L dwell group and 0.89 in the 2.5-L dwell group. For D/P urea, the correlation coefficients were 0.74 and 0.81, respectively. For dialysate to initial dialysate ratio for glucose (D/Do glucose), the correlations were 0.52 and 0.51, respectively.

Figure 1. Comparison of D/P ratios of creatinine (Cr) derived from the 4-h standard PET and the adjusted 24-h dialysate collection. The line of identity is the solid black line. The regression equation is 24-h D/P creatinine = 0.82 (4-h D/P creatinine) + 0.162.

Figure 2. Comparison of D/P ratios of urea derived from the 4-h standard PET and the 24-h dialysate collection. The line of identity is the solid black line. The regression equation is 24-h D/P urea = 0.73 (4-h D/P urea) + 0.244.

Journal of the American Society of Nephrology
wished 0.84 ± 0.007 from the PET and 0.86 ± 0.007 from the DATF, whereas the final D/P value was 0.83 ± 0.06 from the PET and 0.83 ± 0.08 from the DATF. The absolute value of the mean difference and standard deviation between the first and second evaluation for D/P creatinine was 0.05 ± 0.03 for the PET and 0.06 ± 0.06 for the DATF. The absolute value of the mean difference and standard deviation for D/P creatinine between the PET and the DATF was 0.06 ± 0.05.

**Patient Survey**

Thirty-two study patients who underwent the 24-h dialysate collection via the nonprotocol method completed a questionnaire designed to assess patient preferences and problems of the standard PET, the fast PET, and the 24-h dialysate collection. This subgroup of patients had a mean age of 50.1 yr (range, 22 to 80 yr) and a mean time on peritoneal dialysis of 24.2 months (range, 5 to 80 months), with 50% male and 62.5% white patients. Patients overwhelmingly preferred the 24-h dialysate collection (81.3%) to either the standard PET (12.5%) or fast PET (3.1%; 3.1% had no preference; χ² = 99.8; P < 0.001 by the one-way χ² test). Patients had significantly less inconvenience from performing the 24-h dialysate collection than either the long or short PET (paired randomization test, P < 0.001 for mean drain volume in patients with 24- vs 2.5-L dwell volumes.

None of the survey patients experienced any discomfort during the performance of any of the three test types.

**DISCUSSION**

We have demonstrated that, for routine clinical applications, the DATF can be used not only as a measure of daily dialysis clearance but also for the determination of peritoneal transport in adult CAPD patients who undergo four exchanges per day. Using the DATF, a clinician can obtain a true measure of the patient's daily dialysis clearance of urea and creatinine and does not need to rely on potentially inaccurate estimations of clearance derived from PET data (4). In addition, after baseline 24-h D/P creatinine, D/P urea, and drain volume are obtained, the serial use of these parameters can be used to monitor changes in transport and ultrafiltration.

We propose that both the DATF and PET be performed shortly after the initiation of peritoneal dialysis. The patient's dwell volume, dialysate glucose concentrations, and approximate times of exchange will be recorded for the 24-h period that the DATF was obtained. We have not chosen a specific time for this initial evaluation, because there is some controversy regarding the potential for changes in peritoneal transport in the first several weeks of peritoneal dialysis (13). For subsequent clinical follow-up of patients, the D/P values obtained from the DATF should be quite adequate, because in clinical practice, extreme accuracy in estimating D/P values is not required. Therefore, after the initial DATF, the DATF would then be performed every 4 months in order to determine the peritoneal clearance of creatinine and urea for 24-h D/P creatinine and D/P urea values. Information from the DATF can also be combined with information from the simultaneous 24-h collection of urine for creatinine and urea in order to calculate either the weekly Kt/V urea and/or the weekly creatinine clearance normalized to body surface area.

For the performance of the DATF, it is not necessary for patients to use the standardized protocol that was followed by the protocol patients in this study. How-
ever, it is important that the patient follow the same dialysis prescription and exchange times each time the DATT is performed. To ensure that this requirement is met, we recommend that the dialysis unit record the dwell volume, dwell time, and osmotic strength of each of the four exchanges used to calculate the DATT. In practice, we did not observe that this requirement was difficult for patients to follow because most of them follow a standard dialysis prescription that does not vary to a significant degree from day to day. However, if the dwell time, the dialysate osmotic strength, or the dwell volume has changed, then a repeat DATT should be performed in order to assess whether these changes have resulted in a change in either peritoneal creatinine or urea clearance (14), as well as to establish a new DATT baseline. The 24-h drain volume can be used as a direct measure of ultrafiltration in lieu of the PET drain volume. Thus, repeated DATT can be used in the same manner as repeated PET to help determine the cause of inadequate dialysis. If a problem with ultrafiltration or dialysis dose is encountered that is not readily explained by the DATT, then a standard PET can be obtained and compared with baseline PET data.

The use of the DATT is consistent with recent evidence that suggests that knowledge of daily dialysis and urine clearances are necessary to monitor the appropriateness of a patient’s CAPD prescription. A growing body of evidence has documented the importance of providing a certain minimal amount of peritoneal dialysis to prevent excess morbidity and mortality (15-19), and several authors have introduced the concept of optimal peritoneal dialysis as a theoretical approach to further improve the quality of life in CAPD patients (1,20). A number of different methods have been proposed to determine the adequacy of dialysis, including creatinine clearance (19,21), Kt/V urea (16,22,23), and dialysis index (24). Clinical studies in small numbers of patients have provided the clinician with some limited information regarding the minimal amount of peritoneal dialysis that should be provided. For example, Blake et al. have reported that a weekly creatinine clearance of less than 50 L/wk results in an increased risk of mortality (19), whereas Teehan et al. have observed an increased risk of mortality if Kt/V urea (expressed in terms of hemodialysis equivalents) is less than 0.63 (15). Several large-scale clinical trials are presently underway that will provide additional guidelines regarding not only minimal dialysis dose but also which parameters obtained from the 24-h dialysis and urine collections are the best predictors of morbidity and mortality.

There are several advantages to using the DATT in lieu of the PET for the determination of peritoneal transport. First, there is a potential for significant cost reduction by using the 24-h dialysate collection. These cost reductions per test include a personnel savings of $11 (40 min to supervise the standard PET versus 10 min to perform a 24-h dialysate collection, assuming a salary of $22/h, including fringe benefits), one less set of dialysate laboratory determinations, and the need for fewer examination rooms for CAPD patients. Second, the use of DATT provides for the actual measurement of peritoneal transport using the typical dwell volumes and osmolalities of the patient. Third, the information from the DATT can be directly used to determine dialysis clearance, instead of relying on estimation of the 24-h dialysis clearance from PET data. Fourth, estimation of lean body mass can be determined from the DATT and information from a simultaneous 24-h urine collection. Serial estimates of lean body mass can be used to assess for changes in the overall nutritional status of CAPD patients (7). Finally, our group of CAPD patients preferred the DATT to the PET for the determination of peritoneal transport. Although the general impression in the nephrology community is that patients do not prefer to bring in 24-h dialysate collections, we were unable to locate any studies to support this claim. Our patients overwhelmingly preferred this technique to the standard PET, which required at least one exchange to be performed in the dialysis unit as well as the time required to perform either a standard or a fast PET. In addition, a variety of new techniques have been suggested in order to simplify the measurement of 24-h peritoneal drain volume and 24-h peritoneal clearance, including the use of dialysate sampling techniques (25), as well as the weighing of dialysate bags to determine volume (26). These methods may further simplify the performance of the DATT.

Our findings demonstrate that the DATT can be used in a clinical setting to determine daily dialysis clearance and to monitor transport characteristics in adult CAPD patients who undergo four exchanges per day. We have shown that there was a good correlation between transport characteristics derived from the PET and those from the 24-h dialysate collection. The DATT was well accepted by patients and provides a significant cost savings compared with the use of the PET. Further studies will be needed to determine the utility of the 24-h dialysate collection in lieu of the PET in the long-term follow-up of transport characteristics in CAPD patients and in the evaluation of transport characteristics in CAPD patients undergoing three or five exchanges per day, in children on CAPD, and in intermittent peritoneal dialysis patients.

ACKNOWLEDGMENTS

This project was supported by funds from the Piedmont Dialysis Center Research Fund of Winston-Salem, NC. The authors thank the nurses and patients of the home training unit for their efforts and support of this study.

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