Long-Term Follow-Up of Body Size Indices, Residual Renal Function, and Peritoneal Transport Characteristics in Continuous Ambulatory Peritoneal Dialysis

Technique survival in continuous ambulatory peritoneal dialysis (CAPD) depends mostly on clearances in relation to body size and residual renal function (RRF). Our clinical impression has been that when RRF fails, larger patients leave CAPD sooner than smaller patients do.

Peritoneal equilibration tests (PETs) and 24-hour adequacy evaluations performed in 277 patients in a single center from 1986 through 2009 were abstracted from the existing peritoneal dialysis adequacy database. A PET (using 2 L of 2.5% dextrose dialysis solution) was performed in 272 patients during the first 4 months of dialysis. Every 3 months, the patients brought their 24-hour urine and dialysate collections for adequacy evaluations and had height and weight recorded. Body surface area (BSA), body mass index (BMI), and total body water (TBW) were calculated.

There were 1372 adequacy evaluations abstracted. The number of patients gradually declined over time because of death (28%) or transfer to other peritoneal regimens (25%) or to hemodialysis (23%). A small number of patients received a kidney graft (6%) or left CAPD for other reasons (12%); only 6% of patients remained on CAPD after 80 months of treatment. The mean (± standard deviation) PET 4-hour values were 0.652 ± 0.128 for dialysate-to-plasma (D/P) ratio of creatinine (Cr), 0.403 ± 0.0969 for 4-hour dialysate–to–initial dialysate (D/D0) glucose concentration ratio, and 2336 ± 211 mL for the drain volume. There was no correlation between PET D/P Cr and BSA (r = 0.0051, p = 0.934), PET D/D0 glucose and BSA (r = 0.0042, p = 0.945), or PET drain volume and TBW. The correlations with other size indicators were very poor. None of the large patients (BSA > 1.9 m², weight > 75 kg, BMI > 25 kg/m²) remained on CAPD for more than 80 months once they lost RRF.

These results confirm our impression that, with declining RRF, larger patients do not continue CAPD as long as smaller patients do.

Key words
Body size, continuous ambulatory peritoneal dialysis, peritoneal equilibration test, technique survival

Introduction
Technique survival in continuous ambulatory peritoneal dialysis (CAPD) depends mostly on solute and water transfer rates into the dialysate in relation to body size and residual renal function (RRF). In the original study of the peritoneal equilibration test (PET), we found that the dialysate-to-plasma (D/P) solute ratios and drain volumes did not depend on body size: height, weight, or their derivatives such as body surface area (BSA), body mass index (BMI), or total body water (TBW). These data were not published in the original paper on the PET (1).

Based on D/P ratio of creatinine and ultrafiltration volume, we calculated that patients with high transport characteristics would do better on short-dwell exchanges and that patients with low transport...
characteristics would do better on long-dwell exchanges (2). An analysis based on urea kinetics—assuming that a daily protein catabolic rate of 0.8 g/kg shows adequate dietary protein intake and that a minimum weekly Kt/V of 1.7 is achieved—indicated that the maximum weights for CAPD patients reaching those goals and using 4 daily 2-L exchanges were 61 kg for high transporters and 67 kg for low transporters (3,4). A similar analysis for 4 daily exchanges of 2 L, 2.5 L, and 3 L indicated that the weights above which the weekly Kt/V would be less than 1.7 would be 64 kg, 77.6 kg, and 94 kg respectively (5).

The U.S. National Kidney Foundation (NKF) Dialysis Outcomes Quality Initiative (DOQI) guidelines published in 1997 recommended that, to be adequate, weekly Kt/V urea should be kept above 2.0 (6). Those recommendations were based in part on the Canada—U.S.A. (CANUSA) study to evaluate the relationship between clearances in continuous dialysis and clinical outcomes. The study showed that mortality declined as the total (renal plus dialysis) clearance increased (7). No leveling off of the mortality was observed, and an independent effect of dialysis dose on survival was not demonstrated.

In the CANUSA study, almost all patients had substantial RRF, because all patients were observed during the first 2 years of dialysis. All patients remained on 4 daily 2-L exchanges, and thus variations in clearances were related mainly to RRF, and mortality was correlated with RRF rather than with dialysis prescription. It is not surprising that patients with better kidney function survived longer. The recommendation to maintain weekly Kt/V above 2.0 in CAPD was followed in the nephrology community and at our center as well.

At the University of Missouri, the CAPD program started in 1977 (8), and a standardized PET was introduced in 1983 (1). Systematic collection of peritoneal clearances and PET results started in 1986. Over the last 22 years, we have collected a large volume of data. Our clinical impression has been that large patients do not remain on CAPD as long as smaller patients do. In the present paper, we report CAPD technique survival with the use of various exchange volumes as clinically indicated and tolerated by patients.

**Patients and methods**

At a single center, PETs and 24-hour adequacy evaluations performed in 277 patients from 1986 through 2009 were abstracted from the existing PD adequacy database. The standardized PET (9)—using 2 L of 2.5% dextrose dialysis solution—was performed in 272 patients during the first 4 months of dialysis. Every 3 months, the patients brought total 24-hour urine and dialysate collections for adequacy evaluations and had their height and weight recorded. There were 1372 evaluations. Initially, a weekly Kt/V of 1.7 was considered adequate; after the publication of the NKF DOQI guidelines in 1997, a weekly Kt/V of 2.0 was accepted as adequate.

The BSA of the patients was calculated according to the Du Bois and Du Bois formula (10):

\[
BSA (m^2) = 0.007184 \times \text{Height (cm)}^{0.725} \times \text{Weight (kg)}^{0.425}
\]

The BMI of the patients was calculated according to the standard formula:

\[
BMI (kg/m^2) = \frac{\text{Weight (kg)}}{\text{Height (m)}^2}
\]

The TBW of the patients was calculated according to the Watson formulas (11):

\[
\begin{align*}
\text{Male TBW} &= 2.447 - (0.09156 \times \text{Age}) + (0.1074 \times \text{Height}) + (0.3362 \times \text{Weight}) \\
\text{Female TBW} &= -2.097 + (0.1069 \times \text{Height}) + (0.2466 \times \text{Weight})
\end{align*}
\]

Statistical analyses were conducted using Sigma-Stat version 3.5 (Systat Software, San Jose, CA, U.S.A.). The significance of differences was determined using the unpaired Student t-test if normality failed. Correlations were determined using the Pearson product moment procedure. Linear regressions with equations were calculated and plotted using SigmaPlot version 10 (Systat Software).

**Results**

The number of patients gradually declined over time because of deaths (28%), kidney transplantation (6%), transfer to other centers (5%), and transfer to hemodialysis (23%). In addition, patients who did not have an adequate Kt/V or who could not maintain proper fluid balance were moved from CAPD to other peritoneal dialysis (PD) regimens (28%) such as daytime...
ambulatory PD, nightly intermittent PD, nightly tidal PD, or various forms continuous cycling PD (12). One patient recovered kidney function, and 7% of patients were lost to follow-up. Only 3% of patients remained on CAPD at 80 months.

Tables I and II and Figures 1 – 18 show the study results. The PET D/P creatinine was poorly correlated with height, weight, BMI, and TBW (Figure 1); no correlation was evident between the PET D/P creatinine and BSA ($r = 0.0051$, $p = 0.934$, Figure 2). The mean (± standard deviation) 4-hour D/P creatinine from the PETs was 0.65 ± 0.13 (Table I). This mean value is almost identical to that in the original study (1,2): 0.65 ± 0.15.

The 4-hour dialysate–to–initial dialysate (D/D₀) glucose concentration ratio from the PETs was poorly correlated with height, weight, BMI, BSA, and TBW (Figure 3). We observed no correlation between D/D₀ glucose and BSA ($r = –0.0042$, $p = 0.945$, Figure 4). The mean 4-hour D/D₀ glucose was 0.40 ± 0.10 (Table I). This mean value is almost identical to that in the original study (1,2): 0.40 ± 0.10.

The PET drainage volume was poorly correlated with height, weight, BMI, and BSA (Figure 5). We observed no correlation between drain volume and TBW ($r = 0.394$, $p = 0.635$, Figure 6). The mean drain volume was 2336 ± 211 mL (Table I), very close to that in the original study (1,2): 2368 ± 282 mL.

Height remained essentially unchanged from 168.8 ± 9.40 cm at baseline, to 169.6 ± 9.83 cm at 40 months and 167.0 ± 10.74 cm at 80 months (Figure 7, Table II). Weight declined with time on dialysis (Figure 8, Table II). The initial weight of 81.5 ± 19.3 kg remained essentially unchanged up to 40 months (82.6 ± 17.7 kg), but it gradually declined and reached 61.6 ± 14.4 kg at 80 months. The initial BSA of 1.91 ± 0.23 m² remained unchanged up to 40 months (1.93 ± 0.23 m²) and then decreased by 10.5% to 1.69 ± 0.24 m² at 80 months (Figure 9, Table II). The initial BMI of 28.6 ± 6.09 kg/m² remained unchanged up to 40 months (28.6 ± 5.19 kg/m²), but decreased significantly to 21.8 ± 2.80 kg/m² at 80 months (Figure 10, Table II). No patient with a BSA above 1.9 m², a weight above 75 kg, and a BMI above 25 kg/m² remained on CAPD after 80 months. The initial TBW of 38.8 ± 7.6 L remained virtually unchanged at 40 months, but declined significantly to 33.7 ± 6.9 L at 80 months (Table II).

**Table I** Results of initial peritoneal equilibration tests (PETs)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Tests (at 4 hours of the PET)</th>
<th>(n) Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>D/P creatinine</td>
<td>272</td>
<td>0.65±0.13</td>
</tr>
<tr>
<td>D/D₀ glucose</td>
<td>272</td>
<td>0.40±0.10</td>
</tr>
<tr>
<td>Drain volume (mL)</td>
<td>263</td>
<td>2336±211</td>
</tr>
</tbody>
</table>

SD = standard deviation; D/P = dialysate-to-plasma ratio; D/D₀ = end dialysate–to–initial dialysate concentration ratio.

**Table II** Summary of the results at three intervals, mean ± standard deviation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Interval I (0–4 months)</th>
<th>Interval II (40 months)</th>
<th>Interval III (80 months)</th>
<th>$p&lt;0.05$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peritoneal equilibration tests (n)</td>
<td>277</td>
<td>53</td>
<td>9</td>
<td>A, B</td>
</tr>
<tr>
<td>Age (years)</td>
<td>59.6±13.1</td>
<td>61.6±13.6</td>
<td>58.9±9.2</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>81.5±19.3</td>
<td>82.6±17.7</td>
<td>61.6±14.4</td>
<td>A, B</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168.8±9.4</td>
<td>169.6±9.83</td>
<td>167.0±10.74</td>
<td></td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.91±0.23</td>
<td>1.93±0.23</td>
<td>1.69±0.24</td>
<td>A, B</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>28.6±6.09</td>
<td>28.6±5.19</td>
<td>21.8±2.80</td>
<td>A, B</td>
</tr>
<tr>
<td>Total body water (L)</td>
<td>38.8±7.6</td>
<td>40.2±7.6</td>
<td>33.7±6.9</td>
<td>A, B</td>
</tr>
<tr>
<td>Urine volume (mL)</td>
<td>800±724</td>
<td>401±424</td>
<td>382±318</td>
<td>A, C</td>
</tr>
<tr>
<td>Kt/V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urine</td>
<td>0.80±0.74</td>
<td>0.49±0.63</td>
<td>0.42±0.49</td>
<td>C</td>
</tr>
<tr>
<td>Dialysate</td>
<td>1.54±0.36</td>
<td>1.66±0.34</td>
<td>1.86±0.45</td>
<td>A, B, C</td>
</tr>
<tr>
<td>Total</td>
<td>2.35±0.76</td>
<td>2.15±0.54</td>
<td>2.28±0.31</td>
<td>B</td>
</tr>
<tr>
<td>Dialysate D/P Cr</td>
<td>0.75±0.11</td>
<td>0.69±0.10</td>
<td>0.66±0.06</td>
<td>C</td>
</tr>
<tr>
<td>Dialysate volume (mL)</td>
<td>9,135±1,629</td>
<td>10,603±2,531</td>
<td>10,203±3,067</td>
<td>C</td>
</tr>
</tbody>
</table>

A = significant between intervals II and III; B = significant between intervals I and II; C = significant between intervals I and III. D/P = dialysate-to-plasma ratio.
The 24-hour urine volume declined with time on dialysis. The mean initial urine volume of $800 \pm 724$ mL (Figure 11, Table II) declined to $401 \pm 424$ mL at 40 months and to $382 \pm 318$ mL at 80 months. Changes in urine Kt/V over time reflected a lower urine volume (Figure 12), with a mean initial value of $0.80 \pm 0.74$ that declined to $0.49 \pm 0.63$ at 40 months and to $0.42 \pm 0.49$ at 80 months (Figure 12, Table II).

Dialysate Kt/V increased over time (Figure 13, Table II). The initial dialysate Kt/V of $1.54 \pm 0.36$ increased to $1.66 \pm 0.34$ at 40 months and to $1.96 \pm 0.42$ at 80 months. This increase in dialysate Kt/V was related to the increase in 24-hour drain volume (Figure 14, Table II), because the D/P urea remained essentially unchanged. Changes in drain volume were related to changes in CAPD prescription to compensate for decreasing urine volume. As a consequence, the total Kt/V remained essentially unchanged (Figure 15, Table II) from $2.35 \pm 0.76$.

**FIGURE 1**: Dialysate-to-plasma (D/P) ratio of creatinine in the initial peritoneal equilibration test (PET) plotted against size indicators.

**FIGURE 2**: Dialysate-to-plasma (D/P) ratio of creatinine in the initial peritoneal equilibration test (PET) plotted against body surface area.
initially to $2.15 \pm 0.54$ at 40 months and to $2.28 \pm 0.31$ at 80 months.

Urine creatinine clearance gradually declined with time (Figure 16). Mean dialysate D/P creatinine declined slightly (Figure 17, Table II) from a baseline of $0.75 \pm 0.11$ to $0.69 \pm 0.10$ at 40 months and to $0.66 \pm 0.06$ at 80 months. The ratio of dialysate creatinine clearance to BSA gradually increased because of the increased dialysate drain volume (Figure 18).

**Discussion**

The differences in PET results between our original study of 102 patients and the present study of 272 patients are minuscule. The original study involved patients of varying dialysis vintage on PD; in the present study, only the first PET after catheter implantation was taken into account. That change might have contributed to the tiny differences, because the

![Figure 3](image1.png)  
*Figure 3: End dialysate-to-start dialysate (D/D₀) glucose concentration ratio in the initial peritoneal equilibration test (PET) plotted against size indicators.*

![Figure 4](image2.png)  
*Figure 4: End dialysate-to-start dialysate (D/D₀) glucose concentration ratio in the initial peritoneal equilibration test (PET) plotted against body surface area.*
FIGURE 5  Drain volume in the initial peritoneal equilibration test (PET) plotted against size indicators.

FIGURE 6  Total body water plotted against peritoneal equilibration test (PET) drain volume.

FIGURE 7  Height plotted against time on continuous ambulatory peritoneal dialysis (CAPD).
population in central Missouri has remained essentially unchanged.

The data clearly show a substantial drop in the proportion of patients remaining on CAPD with passing time. Only 9 of 277 patients remained on CAPD at 80 months. Among the study patients, 12% moved to other centers or were lost to follow-up; the remaining patients were transferred to other PD regimens or to hemodialysis, or they died. Transfer from CAPD was determined by nephrologists using a combination of clinical assessment and dialysis adequacy measures.

The present study confirms our impression that larger patients do not remain on CAPD as long as smaller patients do, mostly because of inadequate clearances or difficulties in excess volume removal.

The literature contains conflicting data regarding the size of patients and survival on CAPD. Fried et al. (13) found no significant correlations for patient weight or BSA with patient or PD technique survival up to 60 months of observation. In that study, a transfer to automated PD was not considered a CAPD technique failure; by contrast, in our study of CAPD...
technique survival, a transfer to automated PD was considered a CAPD technique failure.

The data from Australia and New Zealand indicate that obesity at the commencement of renal replacement therapy is a significant risk factor for death and technique failure except among patients of New Zealand Maori or Pacific Islander origin, for whom no significant relationship between BMI and death during PD treatment was observed. The difference in the remaining population was already seen at 60 months (14).

In 331 patients, Tzamaloukas et al. (15) found no association between PET D/P creatinine and any size indicator, except for a weak association between D/P creatinine and TBW. Our results are almost identical to those of the Tzamaloukas group and show that, as compared with small patients, large patients have lower normalized small-molecule clearances.

Conclusions
It is highly unlikely that large patients (BSA above 1.9 m², weight above 75 kg, BMI above 25 kg/m²)
can stay on CAPD after 80 months once they lose RRF. It is possible that diffusive peritoneal surface area is poorly related to adult body size. Because clearances are scaled to BSA and TBW, they are insufficient in large patients who lose RRF, and thus the patients discontinue CAPD.

Kaplan–Meier survival curves relative to patient race, sex, body size indicators, and peritoneal transport characteristics will be the subject of another study.

References

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