Peritoneal Equilibration Test Results Are Different in Infants, Children, and Adults1,2

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ABSTRACT
Peritoneal equilibration test (PET) curves have been standardized in adult peritoneal dialysis (PD) patients. However, it appears that norms for pediatric PD patients may be different. A series of PET in 29 stable, chronic PD patients ≤14 yr old performed at dwell volumes of 33 ± 6 mL/kg with 2.5% Dianeeal is reported. PET results for glucose and creatinine transport were compared between patients age ≤2 and those 3 to 14 and published adult values by analysis of variance. Children ≤2 transport glucose and creatinine more rapidly than do children 3 to 14 and adults. Children 3 to 14 transport glucose more rapidly than do adults; creatinine transport is not significantly different. These data demonstrate that transport characteristics differ between very young children, older children, and adults. Because PET are usually performed to plan mode of therapy, to address inadequate ultrafiltration, or to increase clearance, awareness of these results should assist in the clinical care of children on PD.

Key Words: Peritoneal dialysis, pediatric, glucose transport, creatinine transport

Nomtative results for adult peritoneal equilibration test (PET) curves have been described for 2-L dwell of 2.5% Dianeeal (Baxter Healthcare Corp., McGaw Park, IL), yet similar, nomtative curves have not been established for children. Pediatric nephrologists caring for very young children have observed their limited ultrafiltration on chronic ambulatory peritoneal dialysis (CAPD), demonstrating the advantage of modes of therapy using short dwells, such as chronic cycling peritoneal dialysis (CCPD). Most recent data indicate that 70% of children receiving peritoneal dialysis are on automated (cycler-based) therapy (1). Some investigators report higher permeability-surface area products in young children when compared with adults (2–4), whereas preliminary results from other groups have not disclosed such differences (5). We have previously reported a series of PET in children and demonstrated that some have permeability-surface area products outside the adult range (6). We have now extended our observations in order to compare PET results from our youngest peritoneal dialysis patients with those from older children and adults.

METHODS
We performed PET in 29 stable, chronic peritoneal dialysis patients ≤14 yr old according to a protocol described previously (7). PET were performed according to Twardowski (8) with modifications necessitated by patient size and exchange volume. Only one PET per patient was analyzed, and no patient was studied within a month of an episode of peritonitis. The PET was performed in the morning after an overnight dwell for CAPD patients (N = 9). CCPD patients (N = 20) drained their daily fill volumes immediately before the test via standard procedure. Once the abdomen was completely drained of dialysate, the patient was filled with his/her usual volume (33 ± 6 mL/kg) of 2.5% Dianeeal. Once filled, an empty Viaflex container was attached to the Ultrasat Y-tubing (Baxter Healthcare Corp., McGaw Park, IL), and a gram scale was used to determine outflow volume. Sampling times were the same for CAPD and CCPD patients. At appropriate times, 10% of initial fill volume (or a minimum of 20 mL) was drained into the attached bag, a sample was removed (not more than 2% of fill volume), and the remainder was reinfused, leaving the Viaflex (Baxter Healthcare Corp., McGaw Park, IL) bag empty. For infants who could not tolerate at least 150 mL of inflow volume, the "dead space" of the Ultrasat Y-tubing was eliminated by cutting the tubing near the spike and connecting the spiked Viaflex bag to the patient's transfer set by means of a sterile double male luer connector. Dialysate creatinine and glucose were measured at Time 0, 30, 60, 120, 180, and 240 min, and blood was sampled at 120 min. Creatinine was determined by the alkaline picrate method (coefficient of variation [CV], 1.17% at 6.5 mg/dL), and glucose was determined by the glucose oxidase method (CV, 0.98% at 263 mg/dL), with the Synchron CX3 (Beckman, Brea, CA). Dialysate creatinine was corrected for glucose interference.

Patient data were stratified by age ≤2 and 3 to 14 and were compared with published adult values (9). Data are reported as mean ± SD and were analyzed by the use of an analysis of variance (ANOVA) separately for D/P creatinine (ratio of dialysate and plasma creatinine concentrations) and D/D0 glucose (ratio of timed and initial dialysate glucose concentration). Adults were compared with children ≤2 and children 3 to 14 by the use of a two-way ANOVA, with means and standard deviations (10). Patients ≤2 were compared with those age 3 to 14 by means of an ANOVA, with individual patients’ transport data at each time. Comparisons were considered significant if P < 0.05.
RESULTS

Children age ≤ 2 transported creatinine more rapidly than did either older children (age 3 to 14) or adults (Table 1 and Figure 1), with mean differences in D/P creatinine of 0.17 (younger versus older children, P < 0.01) and 0.20 (younger versus adults, P < 0.01), respectively. Creatinine transport did not differ significantly when older children and adults were compared.

Younger children transported glucose more rapidly than did either older children or adults (Table 1: Figure 2), with mean differences in D/D₀ glucose of 0.11 (younger versus older children, P < 0.01) and 0.21 (younger versus adult, P < 0.01), respectively. Similarly, older children transported glucose more rapidly than adults, with a mean difference in D/D₀ glucose of 0.08 (P < 0.01).

The inflow volumes at which patients were studied did not differ between age groups: 31 ± 6 mL/kg for children ≤ 2 and 33 ± 6 mL/kg for those age 3 to 14 (unpaired t test, two-tailed P = 0.63). Drain volumes were compared with inflow volumes for younger and older children. Mean drain volumes after the PET were significantly greater than the mean inflow volumes in the subjects age 3 to 14 (drain volume, 38 ± 9 mL/kg; mean difference between inflow and drain, 4.3 mL/kg; paired t test, two-tailed P = 0.004). Mean drain volumes were less than inflow volumes in subjects age ≤ 2 (drain volume, 23 ± 3 mL/kg) but did not achieve statistical significance because of limited sample number. Adult values are reported for 2-L exchanges, without reference to patient size (9).

DISCUSSION

Our data demonstrate significantly enhanced peritoneal transport of glucose and creatinine in children age ≤ 2 compared with those age 3 to 14 and compared with adults. Older children also demonstrated greater glucose absorption compared with published adult values, although they did not differ in creatinine transport.

Our results are consistent with those of other investigators. Geary et al. studied children age 0.8 to 17.8 yr at very similar dwell volumes (approximately 30 mL/kg) (3). Although data were not presented so as to allow comparison of the youngest and oldest patients in their series, their patients were clustered within high and high-average membrane permeability, as defined by Twardowski (8). In a study of six children (age 2 to 13) at fill volumes of 40 mL/kg, Mactier and colleagues reported significantly greater glucose absorption rates and peritoneal creatinine clearances in children compared with adults (11). Another study of children > 3 yr of age, also at 40 mL/kg, demonstrated higher mean D/P creatinine and lower D/D₀ glucose than those reported for adults, although some patients still fell into the low and low-average permeability ranges (2). A study of peritoneal dialysis efficiency in dogs also demonstrated greater dialysance of urea and inulin in puppies compared with adult dogs (12).

Other investigators have chose to perform PET at volumes scaled to body surface area rather than weight. One such study in children demonstrated that at dialysate volumes of 30 mL/kg, glucose absorption and urea transport curves in children < 3 appeared different from those of older children; when dialysate volume was increased to 1,200 mL/m², these differences were no longer apparent (13). Unfortunately, these PET were performed at a nonstandard Dianeal concentration (1.5%) and glucose data were presented as absolute values rather than as D/D₀ glucose, as Twardowski had originally specified (8); thus, comparison with previous studies is difficult. In addition, creatinine transport was not reported in this study, so one cannot directly compare their findings with those of other studies in children or with adult standards. The study by Schaefer et al. of PET performed at 1,000 mL/m² showed higher D/P creatinine values in children when compared with adults (14). Likewise, other investigators studying children at 1,200 mL/m² confirmed more rapid solute diffusion in children compared with adults (4). Their data are consistent with ours by demonstrating differences in glucose transport at all ages when compared with adults, but differences in creatinine transport only when comparing young children (< 12 yr old) with adults. However,

**TABLE 1. PET results**

<table>
<thead>
<tr>
<th>Group/Results</th>
<th>Time (min)</th>
<th>30</th>
<th>60</th>
<th>120</th>
<th>180</th>
<th>240</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age ≤ 2 (N = 6)</td>
<td></td>
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<td></td>
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<tr>
<td>D/D₀ glucose</td>
<td>0.66 ± 0.07</td>
<td>0.47 ± 0.09</td>
<td>0.33 ± 0.08</td>
<td>0.28 ± 0.08</td>
<td>0.18 ± 0.09</td>
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<tr>
<td>D/P creatinine</td>
<td>0.44 ± 0.10</td>
<td>0.61 ± 0.13</td>
<td>0.76 ± 0.12</td>
<td>0.82 ± 0.12</td>
<td>0.91 ± 0.11</td>
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<tr>
<td>Age 3 to 14 (N = 23)</td>
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<tr>
<td>D/D₀ glucose</td>
<td>0.72 ± 0.11</td>
<td>0.61 ± 0.10</td>
<td>0.45 ± 0.10</td>
<td>0.37 ± 0.12</td>
<td>0.31 ± 0.08</td>
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<tr>
<td>D/P creatinine</td>
<td>0.31 ± 0.08</td>
<td>0.44 ± 0.10</td>
<td>0.57 ± 0.11</td>
<td>0.65 ± 0.14</td>
<td>0.74 ± 0.10</td>
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<tr>
<td>Adults (Ref. 8)</td>
<td></td>
<td></td>
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<tr>
<td>D/D₀ glucose (N = 42)</td>
<td>0.81 ± 0.07</td>
<td>0.68 ± 0.08</td>
<td>0.53 ± 0.09</td>
<td>0.46 ± 0.11</td>
<td>0.38 ± 0.11</td>
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<tr>
<td>D/P creatinine (N = 51)</td>
<td>0.32 ± 0.10</td>
<td>0.41 ± 0.12</td>
<td>0.53 ± 0.13</td>
<td>0.61 ± 0.13</td>
<td>0.68 ± 0.13</td>
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</table>
they were unable to demonstrate differences in transport between different age ranges (<4, 4 to 12, and >12) for either solute, perhaps because subjects were stratified into three groups, leaving too few in each group for analysis. Additionally, some of their patients had more than one PET, potentially confounding results by overrepresenting complicated or unstable patients.

Keshaviah et al. have analyzed the relationship between body size, fill volume, and mass transfer area coefficient (KoA) in 2-h PET (15). They studied adults across a sixfold range of fill volumes (0.5 to 3 L) and demonstrated a doubling of mean KoA for urea, creatinine, and glucose as one moved from the 0.5- to the 2-L fill volume and a leveling off at volumes of 2.5 and 3 L. They also noted that the fill volume for peak glucose KoA (1.5 L) was smaller in their smallest patient (body surface area, 1.41 m²) than the corresponding volume (2.5 L) in their largest patient (2.25 m²); these fill volumes normalized to body surface area are approximately 1.1 L/m². A study of PET in 12 children ranging from 0.2 to 19.1 yr showed no difference in KoA when fill volumes of 0.9 and 1.1 L/m² were used, suggesting that they had reached the "leveling off" volume noted above (16). However, a significant difference in the 4-h D/P creatinine was observed between PET at the larger and smaller volumes. In an earlier study by Gruskin et al., diffusion curves of various solutes were measured over 60-min dwells and clearance calculations were made according to dialysate/plasma ratios and dialysate volume (17). In comparing individuals of different size, clearances were scaled for weight and were not different between children 4 and 18 months compared with those 2.5 to 18 yr.

PET provide a measure of permeability-surface area product, rather than of peritoneal permeability, per se (18). In other words, clinical PET studies determine the permeability of the effectively utilized peritoneal surface area; with widely diverging dwell volumes, it is quite possible that any patient's PET results could vary significantly. As noted above, PET studies have been reported in pediatric patients using fill volumes based on either body weight or surface area: in older children (as in adults), one would expect little difference between the two, yet because surface area is relatively larger in very young children and infants (19), there will be a large difference in dwell volumes depending on how one chooses to scale. Thus, if one prescribes dialysis fill volumes at 1,100 mL/m², this may be well tolerated in an older child but yield unacceptably large fill volumes in an infant. Like Alexander et al. (20), who recommended exchange volumes of 35 to 45 mL/kg, we too have chosen to base our dialysis prescriptions on body weight. We are guided, as well, by clinical factors including patient tolerance of abdominal distension, the ability to eat and move, the incidence of hernias, and the adequacy of clearance. These clinical criteria led to the choice of dwell volumes reported in these PET studies. In addition, because clearances in infants on these dwell volumes are usually excellent (because of their demonstrated high D/P creatinine ratios), the advantages of larger volumes are fewer than in older children and adults.

In conclusion, this study used PET to assess peritoneal glucose and creatinine transport, revealing results that differed between infants, children, and adults. These results assist in the clinical care of peritoneal dialysis patients: they verify the clinical impression of limited ultrafiltration in very young patients on CAPD and validate the widespread use of short-dwell (cycler-based) modes of therapy (CCPD and tidal). In addition, we reported previously that
predictions of clearances from PET can help guide therapy and allow the estimation of $K_t/V$ and creatinine clearance that will be obtained by a given dialysis prescription; one can also modify the prescription to target a specific level of dialysis clearance (6). It has, of course, been our practice to verify predictions by dialysate collection, but we save time and effort by our initial estimation. Because the goal of performing PET is to guide therapy in usual clinical practice, either to plan an initial prescription, to address inadequate ultrafiltration, or to increase clearance when dialysis dose is inadequate, we and others have used usual dwell volumes in conducting these tests. Such protocols demonstrate differences in peritoneal transport as a function of age that are relevant to patient care and provide meaningful comparison with published standards.

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REFERENCES
