

Original Article

Glucose absorption in nephropathy patients receiving continuous ambulatory peritoneal dialysis

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Objectives: Peritoneal dialysis patients are at risk of glucose absorption from peritoneal dialysate, not only because of energy imbalance but also the toxic effects of high glucose. The current widely applied formulae may be not suitable for estimation of glucose absorption in continuous ambulatory peritoneal dialysis (CAPD) patients. This study examined the actual glucose absorption in a cohort of CAPD patients and compared the results with estimates from four current formulae. **Methods:** We conducted a survey of glucose absorption of a cohort of 72 CAPD patients and compared actual dialysate glucose absorbed and estimates using K/DOQI formula, *Grodstein* formula, *Bodnar* formula, or a percentage estimate of 60%. **Results:** The total dialysate glucose infused each day varied from 54.4 to 191 g/day with average of 102±27.9 g. The average of glucose absorbed was 65.7 g (ranging from 19.5 to 131 g) by actual measurements. The mean absorption rate was 64.4% (ranging from 30.6% to 92.4%). The glucose absorbed from dialysate accounted for 13.8% (ranging from 5.0% to 30.1%) of total energy intake. The average errors of absolute values between actual measurements and estimates were greater than 10 g or 20 g glucose ($p<0.001$). The average errors in percentages were greater than 20% or 40%, dependently on estimating methods. **Conclusions:** The applications of current estimating methods may have limitations. The actual measurement provides dietitians and doctors with more exact information of absorbed glucose and energy compared to the current estimating methods.

Key Words: glucose absorption, actual measurement, estimating methods, continuous ambulatory peritoneal dialysis, dietary survey

INTRODUCTION

Since its introduction in 1975, peritoneal dialysis (PD) has become the major alternative modality to hemodialysis and is used by 10%-20% uremic patients worldwide. By the end of 2012, there were 38,000 patients in China treated with PD (27,000 at the end of 2011) and 80% of them were continuous ambulatory peritoneal dialysis (CAPD) patients, most of them using glucose-based PD solutions.¹ Glucose can be absorbed and may provide a considerable source of energy to patients receiving CAPD. Standard dialysates containing 1.5%, 2.5%, or 4.25% dextrose monohydrate actually contain about 1.36, 2.27, or 3.76 g/dL of glucose, respectively. Due to a positive glucose gradient existing, probably patients have never been in a strict fasting state even after a dwell time of six hours with 1.36% glucose solution.² It had been reported that about 60% of the daily dialysate glucose load was absorbed, which resulted in a net glucose absorption average of 182±61 g per 24 hours in North American patients with normal peritoneal transport capacity.^{3,4} Energy intake from dialysate glucose was 8.4±2.8 kcal per kg

body weight per day, or 20.3% (ranging from 12% to 34%) of total energy intake.

Glucose and reactive glucose metabolites, in particular, glucose degradation products which are produced during heat sterilization of dialysate, may induce morphological and functional alterations of the peritoneum.⁵ Besides their local damage on peritoneum, glucose absorption may also contribute to adverse metabolic effects such as hyperlipidemia, hyperglycemia, and hyperinsulinemia. A

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study in 145 Chinese patients showed peritoneal transfer capacity-related hyperglycemia after 12 month of CAPD.⁶ After absorption from the peritoneal cavity into the systemic circulation, glucose and its metabolites cause systemic toxicity, in particular, renal and cardiovascular damage.^{7,8} Cardiovascular death, the most frequent cause of death in PD patients, accounts for 50% of the total deaths.⁹ The mortality from cardiovascular diseases is nearly tenfold higher in patients with end-stage renal disease on dialysis than in the general population (US Renal Data System, USRDS 2013 Annual Data Report). An evaluation among patients with chronic kidney disease (CKD) under conservative treatment (predialysis), on hemodialysis, and on peritoneal dialysis showed that peritoneal dialysis seemed to exert a significant proinflammatory effect on the endothelium. This effect could be related to the high glucose concentrations and glucose degradation products presented in the dialysis fluid.¹⁰ Thus, studies on peritoneal glucose absorption are of importance for the investigation of metabolic effects of CAPD on both energy intake and toxic effects from peritoneal dialysate.

There are four main methods to determine glucose absorption, including direct measurement of glucose absorption from dialysate per day, and estimating methods based on *Grodstein* formula, on D/D₀ formula from peritoneal equilibration test (PET), and simply on an absorption rate of 60%.¹¹ Though direct measurement of glucose absorbed is an accurate method, the estimation based on *Grodstein* formula is usually used for its convenience. However, this currently accepted method of estimating glucose absorption was based on the average glucose absorption of seven CAPD patients.³

Though factors involved in glucose absorption are not fully understood, the dose of peritoneal dialysate seems to be critical. Typically, two liters per bag of standard hypertonic dialysate fluid are used in 92.2% Chinese patients, six liters per day in 34.5% CAPD patients, and eight liters per day in 54.5% CAPD patients.¹ Typically the total glucose infused per day in a Chinese CAPD patient contains no more than 200 g of dextrose monohydrate or 182 g of anhydrous glucose (if a dose of 4 bags of 2.5% dextrose monohydrate is used). Actually 1.5% dextrose monohydrate dialysate is mostly prescribed in China, especially in the first one to two years of CAPD. The differences in other effectors of glucose absorptions, such as dialysis modality, membrane transport characteristics, race, and frame size, may also be very different between Chinese CAPD patients and North American patients.

This study was undertaken to examine the actual glucose absorption and to compare this with the estimates using K/DOQI (the Kidney Disease Outcomes Quality Initiative), *Grodstein*, and *Bodnar* formula in Chinese CAPD patients.

SUBJECTS AND METHODS

Study design and patient population

A cohort study was done in Tongji Hospital, a teaching hospital of Huazhong University of Science & Technology, Wuhan, China. The study protocol was approved by the Hospital Ethics Committee (IRB ID: TJ-C20120501),

and all the subjects signed the informed consent form. The inclusion criteria were non-diabetic nephropathy patients aged greater than 18 years and treated with CAPD for longer than 3 months. Patients who had a recent episode of peritonitis or other infectious complication within 30 days of the dietary assessment were excluded.

Demographic and medical information

Demographic and medical information including gender, age, height, body weight, ethnicity, education, the causes of renal failure, edema, and the starting date of dialysis were collected from the electronic medical records prior to the nutrition interview. The duration of dialysis (in month) was calculated as the interval between the date of initiation of dialysis and the date of the nutrition interview.

Dialysate information

The dialysate used was manufactured by Baxter Healthcare and contained 5% glucose and 2.5% glucose, respectively. The dosage range varied from 4 to 10 L each day and two L per bag of standard hypertonic dialysate fluid were infused into the abdominal cavity and dwelled for 4 hours.

Dietary survey

An experienced dietitian conducted a dietary survey using a 7-d food-frequency questionnaire, which consisted of items in the following eight categories: rice/bread/pasta; milk; meat/fish/eggs; vegetables; fruits; dimsum/snacks; oil/salt; and water. The information on food item, size of each portion, and the number of times of consumption each day or each week was collected. The portion size was explained to subjects using a catalogue of food models or pictures of individual food portions. This questionnaire used allowed an estimation of the average daily dietary intakes of protein (DPI, dietary protein intakes) and energy (DEI, dietary energy intakes).

Measurements of glucose absorbed from dialysate

Method I: The glucose absorbed from peritoneal dialysate was actually measured in the effluent and compared to the grams of glucose that were infused. All effluent dialysates were collected individually with the volume measured per day. Unabsorbed glucose in the efferent dialysate was measured using an automatic biochemical analyzer, which employed the hexokinase method via the reduction of NADP.

Method II: Glucose absorption using the K/DOQI formula (K/DOQI update 2000, http://www.kidney.org/professionals/kdoqi/guidelines_updates/nut_appx03a.html) was used for calculation and comparison.¹⁰ The formula was also derived from *Grodstein* et al.⁴ The quantity of glucose absorbed was estimated as follow: glucose absorbed (g/d)=0.89X-43, where X is the total amount of dialysate glucose infused each day (g/d).

Method III: *Grodstein* formula [1981]⁴: glucose absorbed (g)=(11.3X-10.9)×inflow (L) of dialysate, where X is the average glucose concentration infused.

Method IV: *Bodnar* formula [1993]: glucose absorbed (g)=(1-D/D₀)×X_i, where D/D₀ is the remained fraction of

glucose and X_i is the initial glucose value. This formula takes dialysis modality and membrane transport characteristics into consideration.^{12,13}

Method V: A percentage estimate of 60% from total dialysate glucose infused.

The energy intake from dialysate glucose absorption was calculated by a conversion factor of 16 kJ/g (3.75 kcal/g) glucose according to FAO.¹⁴

Biochemical measurements

Serum biochemistry parameters

The concentration of protein in the serum including albumin was determined. We also measured metal ions including calcium, magnesium, iron, and potassium. Fasting blood glucose was determined to evaluate metabolism status. Creatinine, uric acid, urea nitrogen, and bicarbonate radical were measured to evaluate renal function. All biochemistry measurements were performed by auto-biochemistry analyser machine at the central laboratory of Tongji Hospital.

Parameters in urine and peritoneal dialysis (PD) solution

The volume, urea nitrogen, total protein, albumin and creatinine in 24-h urine and peritoneal dialysis (PD) solutions were determined. The ratio of albumin, normalized protein nitrogen appearance (nPNA), which was calculated with the formula by Teehan et al¹⁵ normalized protein catabolic rate (nPCR), which was calculated using the method by Kopple et al^{16,17} and the value of Kt/V was calculated. All measurements were done in accordance with the national criteria.

Indexes of dialysis adequacy

Weekly total urea clearance (Kt/V) and weekly total creatinine clearance (Ccr), parameters reflecting residual renal function, were calculated from a 24-h collection of dialysate and urine with the use of standard methods.¹⁰ The residual glomerular filtration rate (eGFR) was calculated

as an average of the 24-h urinary urea and creatinine clearances. Total body water was derived by using Watson's formula.¹⁸

Peritoneal equilibration test (PET)

Standard PET was performed to obtain peritoneal creatinine clearance rate (D/PCr) and peritoneal glucose absorption (D/D₀), in which D/D₀ was the ratio of glucose in dialytic drainage at 4 hours vs. that at 0 hour. High transfer was defined by D/PCr as 0.81-1.03, high average transfer as 0.65-0.80, low average transfer as 0.50-0.64, and low transfer as 0.34-0.49.¹⁹

Statistical analysis

Continuous data were expressed as means±SD or medians and interquartile ranges. Analysis of variance was used for between-group comparisons. Post hoc analysis was performed with the Bonferroni method. In stepwise multiple regression analysis, we set inclusive variable standard as $\alpha=0.05$ and exclusive variable standard as $\alpha=0.10$. EpiData 3.0 was used for the double-key data entry and the program control of the data entry. The statistical analysis was performed with SPSS 13.0 (SPSS Inc, Chicago, IL) for WINDOWS.

RESULTS

Clinical characteristics of patients receiving CAPD

The clinical characteristics of the patients are shown in Table 1. The mean age of the 72 patients (40 men and 32 women, all of Chinese origin), was 45.5±13.1 years. The mean duration of CAPD was 21 months (ranging from 3 to 92 months). The mean BMI of CAPD patients was 22 kg/m² and there were six out of 72 patients (8.3%) with BMI less than 18.5 kg/m² while the BMI in 13 patients (18.1%) was greater than 24 kg/m². Fifty three out of 72 patients (73.6%) had the Kt/V over 1.7 and Ccr over 50, which are recommended by Peritoneal Dialysis Standard Operating Procedure of China, as indices for peritoneal dialysis adequacy.

Table 1. Characteristics of the CAPD patients included in the study

	Mean±SD	Median	Minimum	Maximum
Age (year)	45.5±13.1	45	19	73
Body height (cm)	163±8.1	161	143	178
Body weight (kg)	58.3±9.8	58.5	36.0	85.0
BMI (kg/m ²)	22.0±2.9	22.0	14.4	30.8
Duration of uremia (month)	28.1±29.4	20	3	142
Duration of dialysis (month)	20.6±20.9	15.5	3	92
Inflow of dialysate (L)	6.7±1.4	6	4	10
UF (mL/24 h)	236±499	200	-900	1000
Ccr (L/w/1.73 (m ²))	68.8±20.3	65.8	31.3	143
Kt/V	2.03±0.55	2.01	0.95	4.38
nPCR	1.18±0.27	1.16	0.53	1.85
nPNA	0.96±0.22	0.94	0.57	1.68
Serum Na ⁺ (mmol/L)	141±2.3	141	135	148
Serum albumin (g/L)	38.0±4.5	37.9	25.4	48.0
FBG (mmol/L)	5.4±0.9	5.1	4.2	8.9
DEI (kcal/kg b.w./d)	27.0±5.3	27.5	16.9	44.4
DPI (g/kg b.w./d)	0.85±0.25	0.82	0.34	1.69

UF: peritoneal ultrafiltration volume; Ccr: weekly creatinine clearance L/w/1.73 (m²); Kt/V : weekly total urea clearance; nPCR: normalized protein catabolic rate; nPNA: normalized protein nitrogen appearance; FBG: fasting blood glucose; DEI: dietary energy intakes; DPI: dietary protein intakes.

Data of DEI and DPI were estimated according to dietary survey (7-d food-frequency questionnaire). Both DEI and DPI in our cohort were much less than recommendations of US National Kidney Foundation K/DOQI Guidelines (DEI, 35 or 30 kcal/kg body weight per day for <60 years or >60 years, respectively. DPI, 1.0-1.2 g/kg body weight per day).

Comparison of actual measurement and estimates of glucose absorbed (GA) from dialysate

In the 72 CAPD patients, total dialysate glucose varied from 54.4 to 191 g/day with an average of 102±27.9 g per day (Table 2). The average amount of glucose was absorbed was 65.7 g (ranging from 19.5 to 131) each day, by actual measurements. The mean absorption rate was 64.4% (ranging from 30.6% to 92.4%). The mean of glucose absorbed was higher than estimates from four estimating methods, especially compared with the results from K/DOQI formula and Grodstein formula (all $p<0.001$), which was based on the total amount of dialysate glucose infused or the average glucose concentration infused each day. The estimates from Bodnar formula and a percentage estimate of 60% (Method V) of dialysate glucose infused each day were close to the measured amount of glucose absorbed.

Further analysis were performed among 55 patients with standard PET results (D/D₀) using randomized block design ANOVA, and the statistical differences between two groups were calculated by LSD-*t* test. The results are shown (Table 3). The average errors of absolute values between actual measurement and estimates were more than 10 g (Method IV and V) and 20 g (Method II and III) glucose each day ($p<0.001$). The average errors in percentages were more than 20% for Method IV and V, and

40% for Method II and III. Figure 1 compares the estimates using four methods (x axis) with actual measurement (y axis) (Figure 1 A, B, C and D). Coefficients of determination of 0.65, 0.69, 0.59, and 0.65, respectively, were observed. According to PET standard, patients were divided into 4 groups. We combined low transfer group (L) with low average transfer group (LA) in statistical analysis and the results of glucose absorption in 3 PET groups are shown (Table 4). The results calculated by method II and III were much lower than those actually measured (method I) in each PET category ($p<0.01$).

Energy intake from dialysate glucose

The energy intake from dialysate glucose absorption was calculated based on the amount of glucose actually measured. A conversion factor of 16 kJ/g (3.75 kcal/g) glucose was used. The energy intake varied from 1.34 to 8.23 kcal/kg of body weight per day and averaged 4.28±1.51 kcal/kg of body weight per day. In comparison with the average DEI of 27.0±5.3 kcal/kg body weight, the glucose absorbed from dialysate accounted for 13.8% (ranging from 5% to 30%, table 5) of total energy intake. The serum glucose concentration varied from 4.2 to 8.9 mmol/L and was not correlated with glucose absorbed from dialysate ($r=0.02$, $p=0.852$, data not shown).

To minimize the effects of edema which was not rare in CAPD patients, we further analyzed total energy (including from food intake and glucose absorption), and energy derived from glucose absorbed in patients with BMI ranging from 18.5 to 23.9 (Table 6). No difference was observed in average percentage of glucose energy in total energy between before and after adjustment with BMI (14.2% of total energy vs 13.8%).

However, average energy intakes from food carbohy-

Table 2. Glucose absorption according to actual measurement and estimating methods

	n	Mean±SD	X _{min}	X _{max}	P ₂₅	Median	P ₇₅	P ₉₅
Total dialysate glucose (g/d)	72	102±27.9	54.4	191	81.6	99.8	127	145
Method I (g/d)	72	65.7±23.3	19.5	131	48.2	64.6	78.6	112
Method I in percentage (%)	72	64.4±13.6	30.6	92.4	55.2	64.3	77.1	82.9
Method II (g/d)=0.89X-43	72	47.4±24.9*	5.4	127	29.6	45.8	70.0	86.2
Method III (g/d)=(11.3X-10.9)×inflow	72	40.6±19.7*	8.9	106	26.8	35.7	56.3	76.9
Method IV (g/d)=(1-D/D ₀)×X _i	72	59.7±21.2	15.1	121	47.0	58.9	69.2	99.2
Method V (g/d)	72	61.0±16.8	32.6	114	49.0	59.9	76.2	87.1

One way ANOVA, $F_{(4,338)}=17.1$, $p<0.001$; * $p<0.001$, vs actual measurements. Method I, actual measurement; Method II, III, and IV are estimates according to K/DOQI formula, Grodstein formula, and Bodnar formula, respectively. Method V, a percentage estimate of 60% of dialysate glucose infused each day. The results are shown as mean, standard deviation, X_{min}, X_{max} and percentile distribution (P₂₅, Median, P₇₅, P₉₅)

Table 3. Comparison of 4 estimated GA with actual GA (n=55)

Methods	Mean±SD	error= actual-estimate		error(%)= actual-estimate /actual×100%	
		Mean	95% CI	Mean	95% CI
I (g/d)	65.3±24.5	/	/	/	/
II (g/d)	44.7±26.3**	21.7	18.6~24.8	44.2	26.3~62.1
III (g/d)	39.1±20.0**	26.9	23.8~30.0	46.1	36.5~55.6
IV (g/d)	59.5±21.6*	12.8	9.91~15.6	23.0	15.5~30.6
V (g/d)	59.1±17.8**	11.6	9.49~13.8	22.0	13.1~31.0

$F_{(4,216)}=90.53$, $p<0.001$; * $p<0.005$ and ** $p<0.001$, vs Method I.

GA: glucose absorbed; Method I, actual measurement; Method II, III, and IV are estimates according to K/DOQI formula, Grodstein formula, and Bodnar formula, respectively. Method V: a percentage estimate of 60% of dialysate glucose infused each day.

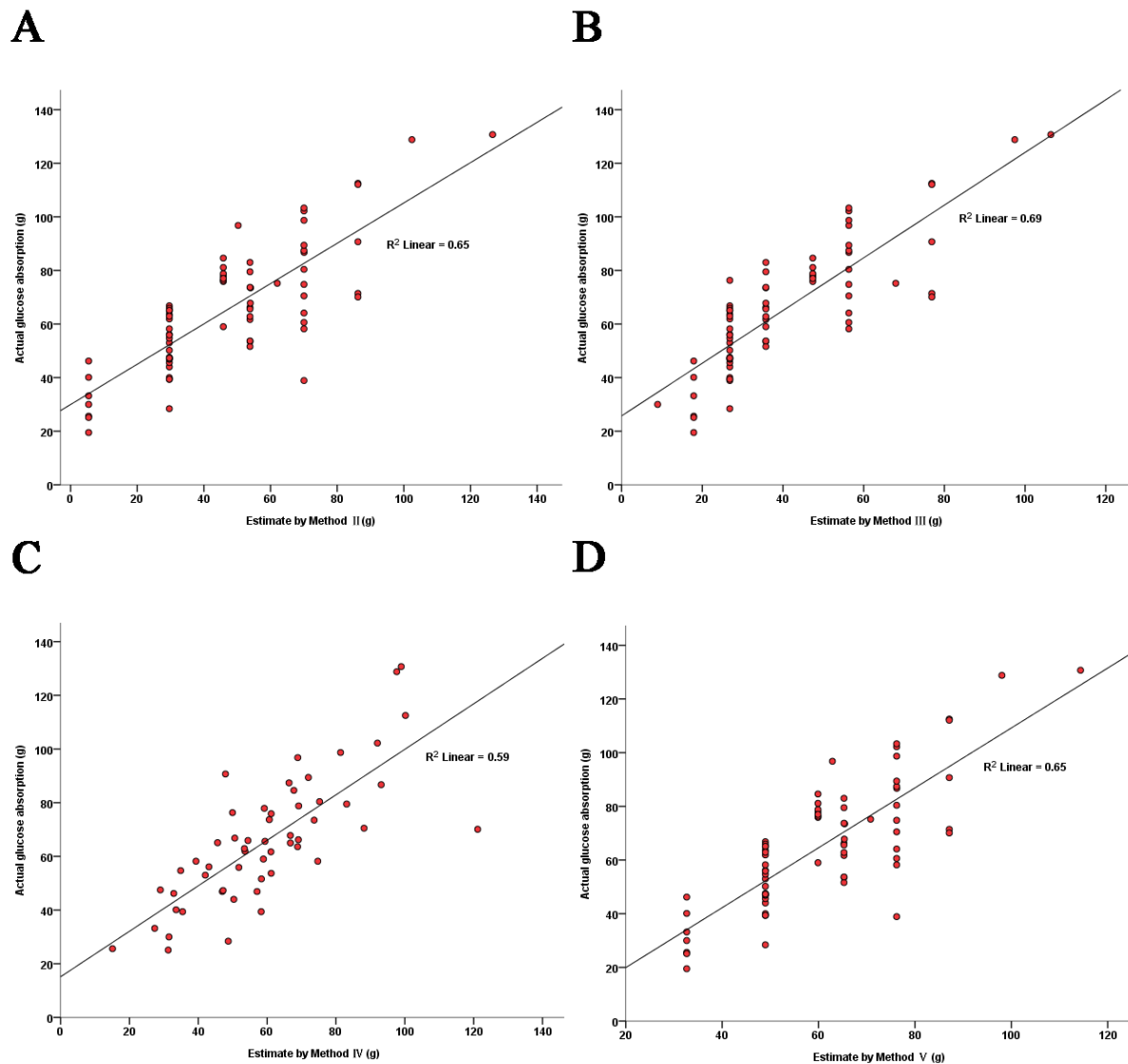


Figure 1. Scatter diagram showing the regression line of Glucose (all units in g) between estimate using Method II (A), Method III (B), Method IV (C), or Method V (D) and actual measurement with coefficient of determination (R^2).

Table 4. Glucose absorption according to actual measurement and estimating methods in 3 PET groups (g/d)

	L+LA (n=20)	HA (n=22)	H (n=13)	Total (n=55)
Method I (g/d)	53.1±17.8	72.3±26.1	78.1±17.4	66.8±23.6
Method II (g/d)	35.7±20.6**	50.2±28.8**	55.1±21.6**	46.2±25.4**
Method III (g/d)	29.8±11.5**	48.0±27.8**	48.1±17.5**	41.7±22.4**
Method IV (g/d)	47.0±17.7	61.5±18.2	78.0±19.6	59.7±21.2
Method V (g/d)	53.0±13.9	62.8±19.4	66.1±14.6	60.1±17.1
<i>F</i>	7.38	3.82	7.16	15.6
<i>p</i>	<0.01	<0.01	<0.01	<0.01

One way ANOVA, ** indicates $p < 0.01$ compared to the Method I. Method I, actual measurement; Method II, III, and IV are estimates according to K/DOQI formula, *Grodstein* formula, and *Bodnar* formula, respectively. Method V, a percentage estimate of 60% of dialysate glucose infused each day. The results are shown as mean±standard deviation.

drate plus glucose absorption accounted for 65.6% of the total energy intake in CAPD patients. A total of 42 out of 72 patients (58.3%) had their energy higher than upper level (65%) of daily carbohydrate intake recommended by Chinese Nutrition Society. Twenty patients (27.8%) were higher than 70% with the highest value being 82.5%.

Stepwise multiple regression model for the factors influencing glucose absorption

The amount of glucose absorbed from peritoneal dialysis each day was the dependent variable, and age, gender, BMI, FBG, serum sodium ion, total dialysate glucose, dwell, Kt/V, Ccr, MAMC, serum albumin, duration of dialysis, peritoneal ultrafiltration volume (UF), and PET

Table 5. Total daily energy intake and energy from glucose absorbed (n=72)

	Mean±SD	X _{min}	X _{max}	P ₂₅	Median	P ₇₅	P ₉₅
Total energy (kcal/kg.day)	31.3±5.57	18.4	46.7	26.6	31.8	35.6	39.2
Glucose energy (kcal/kg.day)	4.28±1.51	1.34	8.23	3.31	4.15	5.07	7.13
Percentage	13.8±4.79	4.96	30.1	10.2	13.1	16.2	23.2

The results are shown as mean, standard deviation, X_{min}, X_{max} and percentile distribution (P₂₅, Median, P₇₅, P₉₅).

Table 6. Total daily energy intake and energy from glucose absorbed in normal BMI patients (n=53)

	Mean±SD	X _{min}	X _{max}	P ₂₅	Median	P ₇₅	P ₉₅
Total energy (kcal/kg.day)	31.4±5.50	18.4	46.7	27.0	32.1	35.5	40.6
Glucose energy (kcal/kg.day)	4.42±1.49	1.46	8.23	3.53	4.21	5.20	7.61
Percentage	14.2±4.85	4.96	30.1	11.2	13.1	16.1	24.4

The results are shown as mean, standard deviation, X_{min}, X_{max} and percentile distribution (P₂₅, Median, P₇₅, P₉₅).

Table 7. Multiple linear regression analysis of factors affecting glucose absorption from dialysate (coefficients)

Predictor	β	95% CI for β	p	Standardized coefficients β
Total dialysate glucose (g/d)	0.60	0.49~0.70	<0.001	0.85
PET	61.9	44.8~79.1	<0.001	0.60
BMI	1.78	0.86~2.71	<0.001	0.36
Ccr	0.25	0.10~0.40	<0.001	0.28
FBG (mmol/L)	-3.29	-5.06~-1.52	<0.001	-0.27
UF (mL/d)	-0.01	-0.01~0.00	0.09	-0.16

R²=0.96; PET: peritoneal equilibration test; Ccr: weekly creatinine clearance L/w/1.73 (m²); FBG: fasting blood glucose; UF: Peritoneal ultrafiltration volume.

were the independent variables. Stepwise multiple regression analysis suggested that total dialysate glucose, PET, BMI, Ccr, and FBG were obviously related to the amount of glucose absorbed, but no significant relationship was found between Kt/V and the amount of glucose absorbed (Table 7). Stepwise multiple regression analysis showed that the six predictors explained 96.2% of the variation in glucose absorption outcome.

DISCUSSION

In the present study, we showed that higher glucose absorption from dialysate was actually detected in CAPD patients compared with estimates using K/DOQI formula, *Grodstein* formula, *Bodnar* formula, or a percentage estimate of 60%. The glucose absorbed from dialysate accounted for 13.8% (range from 5.0% to 30.1%) of total energy intake. We also found that the total dialysate glucose infused each day, serum sodium ion, and ultrafiltration volume were the main influencing factors for glucose absorption, and these three explained 78.9% of the variation.

Glucose-based PD solutions have been linked to many adverse metabolic consequences. Glucose absorption from PD dialysates causes a chronic stimulation of insulin secretion, which leads to hyperinsulinemia. Other adverse effects have been reported including hyperglycemia, hyperlipidemia, obesity, and suppressed appetite. Glucose absorption and the adverse effects had gained attention ever since the beginning of PD.

However, the *Grodstein* formula did not take into account individual variations in glucose absorption due to peritoneal membrane transport differences. Ginsberg et al²⁰ noted a wide range of glucose absorption in 20 CAPD

patients (49.9%-86.4% of the glucose was absorbed). In this study, we also observed that 30.6%-92.4% of the glucose was absorbed in 72 CAPD patients. Due to the differences such as the total amount of dialysate glucose infused each day, membrane transport characteristics, race, and frame size, we found that the average glucose absorption estimated by *Grodstein* formula was much less than actual value (47.4±24.9 or 40.6±19.7 vs 65.7±23.3, $p<0.001$). This finding aroused the debates on whether formula recommended by K/DOQI or *Grodstein* formula are suitable for estimation of glucose absorption from dialysate in China or other countries where the body frame size of CAPD patients are small.

In 1993, *Bodnar* et al derived formula based on PET, and the results based on this formula were closer to actual glucose absorbed (CAPD: $p=0.0153$; APD: $p=0.0001$).¹³ The *Bodnar* formula is individualized for dialysis modality (APD, CAPD) and transport characteristics and is easy to calculate from readily available information. It provides dietitians with an easy-to-use tool to accurately calculate the glucose that peritoneal dialysis patients absorb from the dialysate. However, we observed that the average errors in percentages were more than 20% between actual glucose absorbed and the estimate using *Bodnar* formula. In addition, the coefficient of determination (R²=0.59) between actual measurement and the estimate using *Bodnar* formula is the least among different estimating methods used in our CAPD patients. Though the mean estimate using 60% absorption rate of dialysate glucose in this study was close to actual absorption (61.0±16.7 vs 65.7±23.3, $p<0.01$), the difference is significant and the wide range of glucose absorption in individual CAPD patients makes it difficult to be applied for

individual estimations. Thus the application of the estimate should be prudent.

Peritoneal glucose delivery can also lead to hyperglycaemia and hyperinsulinaemia compared with oral glucose.²¹ It was estimated that a quantity of energy can be absorbed from dialysate glucose. Grodstein et al reported about 8.4±2.8 kcal/kg of body weight per day, or 20.3% (ranged from 12% to 34%) of total energy intake in CAPD patients. Our results were 4.35±1.65 kcal/kg/day, lower than Grodstein's results, however they still accounted for about 14% of total energy intake (ranging from 5% to 30%). Those glucose derived energy not only contributed considerably to total energy intake but also add additional energy to carbohydrate portion of energy and cause imbalance of energy. A recent cohort study showed that higher peritoneal dialysate glucose concentrations are associated with higher all-cause and CVD mortality in CAPD patients.²² In addition, results from a cohort of 75,521 American women (The Nurses' Health Study) suggested that a high dietary glycemic load from refined carbohydrates increases the risk of CHD, independent of known coronary disease risk factors.²³ Furthermore, a recent report on cohort of 117,366 Chinese women and men (Shanghai Women's Health Study and the Shanghai Men's Health Study) indicated that high carbohydrate intake, mainly from refined grains, is associated with increased CHD risk in Chinese adults.²⁴ WHO/FAO recommended free sugars, which refers to all monosaccharides and disaccharides, no more than 10% total energy intakes as Dietary Intake Goals to population.²⁵ In our study, more than 75% CAPD patients absorbed nearly 50 g glucose from peritoneal dialysate alone, equivalent to no less than 10% free sugar intake from dialysate alone, which means that the patients are never in a true fasting state. Furthermore, about 30% (20 patients) of them had more than 70% energy intake from carbohydrate (dietary intake and glucose absorption). Dietitians need pay attention to the imbalance of energy portions and give CAPD patients dietary instruction individually.

As it had been reported, in China the overall prevalence of chronic kidney disease is 10.8% and the number of patients with chronic kidney disease has been estimated to be about 119.5 million.²⁶ There will be more CKD patients who need to be treated with CAPD. Actual measurement of glucose will provide doctors with individual clinical indication and provide dietitians with exact information of absorbed energy.

There are multiple factors influencing the glucose absorption including dialysate, dwell time, and peritoneal characteristics. Although no insight into individual factors have been reported, we found here that total dialysate glucose, PET, BMI, Ccr, FBG and UF explained 96.2% of the variation in glucose absorption outcome using a stepwise multiple regression model. The increasing effect of total dialysate glucose on glucose absorption is quite reasonable in biology. The differences in glucose absorption among PET categories had also been shown in CAPD patients with non-diabetic nephropathy recently.⁶ A relatively higher morbidity from hyperglycemia in the high transfer patients was reported in a 48-month follow-up period in the same study. Therefore the weakness of

methods II and III, which would underestimate glucose absorption, may be partially due to non-consideration of peritoneal transfer status.

In summary, we showed the differences of dialysate glucose absorbed between estimates using K/DOQI formula, Grodstein formula, Bodnar formula, or a percentage estimate of 60% and actual measurement. The application of current estimating methods needs to be re-examined. The actual measurement will provide dietitians and doctors with exact information of absorbed glucose and energy.

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AUTHOR DISCLOSURES

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Original Article

Glucose absorption in nephropathy patients receiving continuous ambulatory peritoneal dialysis

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持续非卧床腹膜透析肾病病人的葡萄糖吸收

目的：从透析液中吸收的葡萄糖不仅会造成腹膜透析病人能量失衡，还会对机体产生毒性作用。但目前广泛应用的葡萄糖吸收量估算公式可能不适合中国的持续性非卧床腹膜透析（CAPD）病人。本文在一个 CAPD 队列中探讨四种估算方法与实测值的差异。**方法：**测量 72 例 CAPD 病人透析液来源的葡萄糖吸收量，并与 K/DOQI 公式、Grodstein 公式、Bodnar 公式以及 60% 葡萄糖吸收率公式的估算结果进行比较。**结果：**CAPD 病人每日使用的透析液所含葡萄糖总量平均为 102 ± 27.9 g（范围 54.4 到 191 g）。葡萄糖吸收量实际测量值平均为 65.7 ± 23.3 g（范围 19.5 到 131g），平均吸收率为 64.4%（范围 30.6%到 92.4%），透析液来源的葡萄糖供能占总能量的比例为 13.8%（范围 5.0%到 30.1%）。实际测量值与四种不同公式估算值平均差值大于 10 g 或 20 g ($p < 0.001$)，平均差值百分比大于 20%或 40% ($p < 0.001$)。**结论：**目前应用的葡萄糖吸收量估算方法存在局限性，与目前使用的估计方法相比，实际测量值可以更准确地为营养师和医生提供葡萄糖和能量的吸收信息。

关键词：葡萄糖吸收、实际测量、估算方法、持续非卧床腹膜透析、膳食调查