PLOS | ONE

RESEARCH ARTICLE

The Association between Nutritional Markers and Biochemical Parameters and Residual Renal Function in Peritoneal Dialysis Patients

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Citation: Li L, Liang W, Ye T, Chen Z, Zuo X, Du X, et al. (2016) The Association between Nutritional Markers and Biochemical Parameters and Residual Renal Function in Peritoneal Dialysis Patients. PLoS ONE 11(6): e0156423. doi:10.1371/journal.pone.0156423

Editor: Jeff M Sands, Emory University, UNITED STATES

Received: January 19, 2016

Accepted: May 14, 2016

Published: June 3, 2016

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Funding: This work was supported by the provincial Science Foundation of Hubei (WJ2015MB011) and the National Science Foundation of China (NSF 81300592). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

Abstract

Residual renal function (RRF) is an important prognostic factor for peritoneal dialysis patients as it influences the quality of life and mortality. This study was conducted to explore the potential factors correlated with RRF. A cross-sectional study was conducted by recruiting 155 patients with residual GFR more than 1mL/min per 1.73m^2 at the initiation of peritoneal dialysis. We collected the demographic characteristics, nutritional markers and biochemical parameters of all participants, and analyzed the correlation between these variables and residual GFR as well. The odds ratio of RRF loss associated with each of the nutritional markers and biochemical parameters were estimated by logistic regression model. The residual GFR was negatively correlated with serum phosphate (OR_{Q3} = 2.67, 95%CI: 1.03–6.92; OR_{Q4} = 3.45, 95%CI: 1.35–9.04), magnesium (OR_{Q4} = 3.77, 95%CI: 1.48–3.63), and creatinine (OR_{Q3} = 2.93, 95%CI: 1.09–7.88; OR_{Q4} = 8.64 95%CI: 2.79–26.78), while positively associated with normalized protein catabolic rate (OR_{Q3} = 0.24, 95%CI: 0.09–0.65; OR_{Q4} = 0.11, 95%CI: 0.03–0.35), 24 hours urine volume(OR_{Q1} = 22.87, 95%CI: 2.76–189.24; OR_{Q3} = 0.08, 95%CI: 0.02–0.28) and serum chlorine concentrations (OR_{Q1} = 5.34, 95%CI: 1.94–14.68; OR_{Q4} = 0.28, 95%CI: 0.09–0.85), respectively. Our study suggested that the nutritional markers and biochemical parameters, though not all, but at least in part were closely correlated with RRF in peritoneal dialysis patients.

Introduction

In recent years, chronic kidney disease (CKD) has become a worldwide public health problem as its rapid increase in the incidence and prevalence. CKD is highly prevalent among adults in both developed [1–3] and developing countries [4]. In 2012, large-scale national survey from China found that the prevalence of CKD was 10.8% [4]. And it was found that 2% of patients with CKD would enter the stage of end-stage renal disease (ESRD), when dialysis or renal transplantation was needed to sustain life. However, most patients prefer to choose dialysis

considering the complications after transplantation and side effects of long-term immunosuppressive agents use. Preserving residual renal function (RRF) is important for survival in patients undergoing peritoneal dialysis (PD) or hemodialysis. It has been demonstrated that 1% elevation of the glomerular filtration rate (GFR) decreased mortality 7–48% [5–8]. For Chinese PD patients, a much closer association was found with a higher residual GFR (1 mL/min per 1.73m^2) reducing 52% relative risk of death [9]. The potential mechanisms underlying these decrease included better fluid removal and blood pressure control, enhanced clearance of middle to large molecular weight uremic toxins, prevention of dialysis-associated amyloidosis caused by the tissue deposition of β2-microglobulin and promotion of hormone synthesis [10–12]. Overhydration with resulting therapy-resistant hypertension and left ventricular hypertrophy is a frequent problem in PD patients [13]. RRF has been proved to be an important determinant in the maintenance of a normal volume status in PD patients [14]. In addition, lower RRF has also been considered as risk factor for depression and impaired health-related quality of life in dialysis patients [15]. Therefore, preservation of RRF is an important goal in the treatment of continuous ambulatory peritoneal dialysis (CAPD) patients.

It has been reported that the loss of RRF was partly due to increased generation of inflammation factors such as C-reactive protein (CRP), intraperitoneal interleukin-6 (IL-6), hyaluronan and neopterin, elevation of the advanced glycation end-product N- "-carboxymethyllysine and fibroblast growth factor 23 (FGF23), and the use of coronary angiography [16–19]. Recent study from Chang *et al* has also found that low serum bicarbonate predicts RRF loss in peritoneal dialysis patients [20].

As an important marker to measure RRF of dialysis patients, glomerular filtration rate (GFR) of residual renal is well correlated with measured total creatinine clearance, less expensive and time-consuming compared to weekly creatinine clearance (wCcr) and Kt/V of residual renal [21]. Thus, the present study was conducted to explore the potential influence factors of residual GFR in Chinese patients with CAPD.

Materials and Methods

Ethics

The study has been approved by the Institutional Review Board of Tongji Hosipital, Tongji Medical College, Huazhong University of Science and Technology. All the patients signed the informed consent about the use of their tissue samples and baseline data in research.

Patients and data collection

This cross-sectional study included 155 end-stage renal disease (ESRD) patients on CAPD treated at Tongji hospital of Wuhan in China from January, 2005 to December, 2015. We retrospectively reviewed their medical records. The inclusion criteria were: 1) having residual GFR more than 1 mL/min per 1.73m^2 before peritoneal dialysis; 2) being under CAPD treatment as the initial renal replacement treatment for at least 3 years; 3) absence of hypoalbuminemic state (nephritic range proteinuria, advanced liver disease, or intestinal malabsorption); 4) absence of a history of atherosclerotic vascular disease at the initiation of PD. A semi-structured questionnaire was used to collect information about age, gender, occupation, education, marital status, history of hypertension or diabetes, etiology of CKD, duration on PD, type of PD solution, number of exchanges per day and erythropoietin dose, dialysis tubing, height and dry weight. Body weight was preferably done with empty abdominal cavity. The Body Surface Area (BSA) was calculated basing on the formula of Gehan and George [22]. The occupation was classified according to the intensity of laboring. Farmers and workers were categorized as high strength work, office clerks and students were classified as moderate intensity work, and

others were light physical activity. Edema was graded degree I if it was local, otherwise graded degree II. The residual GFR was measured at the third year of peritoneal dialysis initiation and calculated base on the formula recommended by Nolph [23]. The equation was: residual GFR = (renal urea clearance + renal creatinine clearance) /2, where renal urea clearance (ml/min) = (urine urea concentration/ serum urea concentration) ×24 h urine volume/1440, renal creatinine clearance (ml/min) = (urine creatinine concentration/ serum creatinine concentration) ×24 h urine volume/1 440.

Meanwhile, nutritional markers and biochemical parameters were measured including normalized protein catabolic rate (nPCR), albumin, total protein, hemoglobin, white blood cell count (WBC), red blood cell count (RBC), hematocrit, platelet, iron concentration (Fe^{2+}), total iron binding capacity (TIBC), transferrin saturation (TSAT), ferritin, intact parathyroid hormone (iPTH), alkline phosphatase (AKP), serum concentration of Calcium (Ca^{2+}), Kalium (K^{+}), Phosphorus (P^{3-}), Sodium (Na^{+}), Chlorine (Cl^{-}), Magnesium (Mg^{2+}), blood glucose, triglyceride (TG), cholesterol (TC), low density lipoprotein (LDL), high density lipoprotein (HDL), aspertate aminotransferase (AST), alanine aminotransferase (ALT), carbon dioxide combining power (CO2-CP), urea, uric acid, creatinine and 24h urine volume. Protein catabolic rate (PCR) was calculated by the formula proposed by Tattersall [24] as follows: nPCR (mg/kg/day) = 1497×G/V +1.7, where G/V = [(Uv × Uc) + (Dv × Dc)]/1440V [Uv = volume of 24 h urine collection; Uc = urine urea concentration in 24 h urine collection; Dv = volume of 24 h collection of spent dialysate; Dc = urea concentration in 24 h collection of spent dialysate.

Statistical analysis

Participants were classified into four groups based on quartiles of residual GFR (Q1, Q2, Q3, Q4), and comparisons among the four groups were conducted. Data were checked for normality first and presented as (mean ± standard deviation) or median (range) for continuous variables, while count (%) value for categorical variables. Comparisons were made by one-way ANOVA or Kruskal-Wallis H test for continuous variables while Cochran-Mantel-Haenszel χ^2 test for categorical variables. The loss of residual renal function was defined as residual GFR less than 1 mL/min per $1.73m^2$. Logistic regression was used to estimate the odds ratio of RRF loss associated with serum biochemical parameters, setting the second quartile as a reference group. Furthermore, trends for the relationships between RRF and biochemical parameters were also tested by comparing the median of residual GFR among groups classified by the interquartile range of biochemical parameters.

The statistical analyses were performed using SAS software (version 9.2.3), and all P-values calculated as two-sided. The data was analyzed as normal distribution if the *P*- value was more than 0.10 while the association was considered significant if it was less than 0.05.

Result

Basic characteristics of patients at study inclusion were given in Table 1. The mean age of the patients was (44.52±13.19) years old, in which 48.39% were males, 25.17% were high strength workers, and 35.48% have history of hypertension or diabetes. The median residual GFR was 1.68 mL/min per $1.73m^2$ (range, 0.00–12.32 mL/min per $1.73m^2$). The mean age of the four groups was not statistically different ((45.17±14.64) vs. (41.53±11.34) vs. (45.39±12.29) vs. (45.95±14.20), $P = 0.450$). And the distribution of residual GFR was not statistically different between male and female ($P = 0.695$), similar results were observed according to the profession of patients ($P = 0.632$), degree of education ($P = 0.702$) and the medical history of hypertension or diabetes ($P = 0.091$).

Table 1. Baseline characteristics of study subjects stratified by the interquartile range of residual GFR.

Variables	Total	residual GFR (mL/min per 1.73m^2)[a]				F/χ^2	*P* [b]
		Q1 (0–0.36)	Q2 (0.36–1.68)	Q3 (1.68–2.99)	Q4 (2.99–12.32)		
age	44.52±13.19	45.17±14.64	41.53±11.34	45.39±12.29	45.95±14.20	0.89	0.450
sex						0.15	0.695
male	75(48.39%)	23(30.67%)	16(21.33%)	14(18.67%)	22(29.33%)		
female	80(51.61%)	16(20.00%)	22(27.50%)	25(31.25%)	17(21.25%)		
occupation						0.92	0.632
high strength work	36(25.17%)	9(25.00%)	10(27.78%)	12(33.33%)	5(13.89%)		
moderate intensity work	46(32.17%)	10(21.74%)	15(32.61%)	9(19.57%)	12(26.09%)		
light physical activity	61(42.66%)	18(29.51%)	9(14.75%)	14(22.95%)	20 (32.79%)		
education						0.71	0.702
primary school or below	37(24.50%)	12(32.43%)	7(18.92%)	10(27.03%)	8(21.62%)		
junior or high school	87(57.62%)	19(21.84%)	24(27.59%)	22(25.29%)	22(25.29%)		
college or above	27(17.88%)	7(25.93%)	6(22.22%)	5(18.52%)	9(33.33%)		
hypertension or diabetes						2.86	0.091
no	100(64.52%)	28(28.00%)	29(29.00%)	19(19.00%)	24(24.00%)		
yes	55(35.48%)	11(20.00%)	9(16.36%)	20(36.36%)	15(27.28%)		

[a] classified into four groups based on quartiles of residual GFR.

[b] Comparisons were made by one-way ANOVA or Kruskal-Wallis H test for continuous variables while Cochran-Mantel-Haenszel χ^2test for categorical variables.

doi:10.1371/journal.pone.0156423.t001

Table 2 showed the comparison of nutritional markers and biochemical parameters among the four groups classified by the interquartile range of residual GFR. Most nutritional markers and biochemical parameters were not statistically different among the four groups. However, the median of 24 hours urine volume in patients with higher residual GFR was significantly higher than patients with lower residual GFR ($P<0.001$). Similar results were found in nPCR ($P<0.001$). Inverse tendency was found in serum concentration of P^{3-} ($P = 0.001$) and creatinine ($P<0.001$). In addition, the mean values of BSA ($P = 0.004$) and the median of Na^+ ($P<0.001$), Cl^- ($P<0.001$) and Mg^{2+} ($P<0.001$) were also found statistically different among the four groups.

Given to potential confounding effects, age and sex were adjusted in the logistic regression model for each of the variables above with *P* value less than 0.05. It showed that higher was always better for nPCR, serum concentration of Cl^- and 24 hours urine volume. Compared to Q2, patients with nPCR among Q3 had a lower risk of RRF loss (OR = 0.24, 95%CI: 0.09–0.65), and 0.11 (95%CI: 0.03–0.35) for patients among Q4. The low level of Cl^- was a risk factor for RRF loss (OR_{Q1} = 5.34, 95%CI: 1.94–14.68) while a protective factor (OR = 0.28, 95%CI: 0.09–0.85) when it was among Q4. For 24 hours urine volume, the risk of RRF loss would increase to 22.87 times (95%CI: 2.76–189.24) when it was among Q1, while decreased to 0.08 (95%CI: 0.02–0.28) when it was more than 550mL compared to the second quartile (200-550mL). For serum P^{3-}, Mg^{2+} and creatinine, higher was always worse. Compared to the second quartile, patients with P^{3-} concentration among Q3 had higher risk of RRF deterioration (OR = 2.67, 95%CI: 1.03–6.92) and 3.45 (95%CI: 1.35–9.04) for patients among Q4. And the risk increased to 3.77(95%CI: 1.48–3.63) when serum Mg^{2+} was among Q3. Similar results were found in serum creatinine (OR_{Q3} = 2.93, 95%CI: 1.09–7.88; OR_{Q4} = 8.64, 95%CI: 2.79–26.78). There was no relationship between RRF deterioration and BSA and serum Na^+. The result was showed in Table 3.

Table 2. Comparisons of nutritional markers and biochemical parameters among the four groups stratified by the interquartile range of residual GFR.

Variables	residual GFR (mL/min per 1.73m^2)[a]				χ^2/F/K	*P*[b]
	Q1 (0–0.36)	Q2 (0.36–1.68)	Q3 (1.68–2.99)	Q4 (2.99–12.32)		
BMI(kg/m^2)					1.48	0.477
<18.5	3(12.00%)	9(36.00%)	8(32.00%)	5(20.00%)		
18.5–23.9	31(28.44%)	27(24.77%)	23(21.10%)	28(25.69%)		
≥24	5(25.00%)	1(5.00%)	8(40.00%)	6(30.00%)		
BSA(m^2)	1.65±0.16	1.53±0.13	1.57±0.17	1.64±0.17	4.61	0.004
Edema					5.69	0.058
No	31(29.25%)	28(26.42%)	25(23.58%)	22(20.75%)		
I	5(14.71%)	6(17.65%)	11(32.35%)	12(35.29%)		
II	3(21.43%)	4(28.57%)	3(21.43%)	4(28.57%)		
nPCR (mg/kg.d)	30.43(17.30–40.01)	31.54(18.18–54.28)	34.87(10.33–58.31)	36.32(22.62–83.09)	21.03	<0.001
Albumin(g/L)	37.70(29.90–45.50)	37.35(22.20–44.50)	37.90(16.90–47.60)	36.65(21.10–43.20)	0.67	0.881
Total protein(g/L)	68.80(57.40–78.90)	70.80(51.00–97.00)	68.20(46.80–83.40)	67.80(52.10–79.60)	2.08	0.556
WBC(10^9/L)	5.95±1.68	6.36±1.88	6.62±2.05	6.18±1.58	0.94	0.425
RBC(10^{12}/L)	3.25±0.71	3.22±0.55	3.41±0.57	3.39±0.57	1.00	0.394
Hemoglobin(g/L)	95.22±21.37	93.97±16.89	100.97±16.41	99.97±17.11	1.44	0.233
Hematocrit(%)	28.20±6.74	28.10±4.94	29.96±4.93	29.75±5.16	1.28	0.285
Platelet(10^9/L)	176.08±67.19	204.38±54.20	200.64±69.52	191.97±56.80	1.56	0.202
Fe^{2+} (μmol/L)	10.22(1.90–35.04)	11.90(4.81–30.15)	12.11(1.73–23.63)	11.76(2.42–34.80)	1.78	0.620
TIBC	46.64±10.01	43.97±9.08	41.98±8.70	41.26±8.53	2.62	0.053
TSAT	20.72(2.35–75.90)	26.08(11.08–85.41)	29.27(5.16–69.24)	30.73(8.96–77.51)	6.61	0.085
Ferritin(μg/L)	158.00(10.10–696.00)	126.90(13.90–766.10)	143.75(18.00–980.00)	187.80(35.80–979.80)	1.80	0.614
iPTH (ng/L)	398.70(38.72–1106.00)	311.35(85.51–1182.00)	315.20(29.40–1198.00)	313.70(19.14–1281.00)	1.97	0.578
AKP (U/L)	77.00(41.00–183.00)	74.00(34.00–385.00)	80.00(40.00–167.00)	74.00(33.00–239.00)	1.51	0.681
Ca^{2+}(mmol/L)	2.36(1.78–2.66)	2.36(1.58–3.02)	2.29(1.64–2.74)	2.27(2.05–3.05)	3.72	0.294
P^{3-}(mmol/L)	2.03(1.01–3.40)	1.66(0.56–3.22)	1.54(0.80–2.73)	1.52(0.46–2.57)	17.14	0.001
K^+(mmol/L)	4.07(2.61–5.79)	4.22(3.33–5.48)	4.02(2.68–5.98)	4.22(2.69–5.84)	0.95	0.814
Na^+(mmol/L)	139.00(131.10–148.40)	138.25(132.90–142.70)	138.70(125.60–142.70)	140.80(131.80–144.80)	22.87	<0.001
Cl^-(mmol/L)	95.60(87.00–135.80)	94.30(85.30–105.00)	96.50(81.90–105.80)	99.60(88.80–105.00)	33.97	<0.001
Mg^{2+}(mmol/L)	1.01(0.69–1.29)	0.84(0.63–1.26)	0.82(0.59–1.31)	0.89(0.62–1.31)	19.46	<0.001
Blood glucose(mmol/L)	5.60(4.24–28.49)	5.24(4.05–8.82)	5.40(3.79–10.59)	5.40(4.51–11.62)	5.06	0.167
TG(mmol/L)	1.25(0.26–5.95)	1.08(0.34–4.15)	1.30(0.23–7.77)	1.29(0.50–5.97)	3.03	0.387
TC(mmol/L)	4.49 (2.58–6.75)	4.59(2.84–8.26)	4.61(2.87–8.32)	4.62(1.88–6.74)	1.72	0.633
LDL(mmol/L)	2.64(1.05–4.59)	2.46(1.11–5.22)	2.62(1.06–5.44)	2.29(0.50–4.23)	3.47	0.325
HDL(mmol/L)	1.06(0.68–10.50)	1.13(0.62–1.95)	1.06(0.51–1.80)	1.07(0.62–2.33)	1.04	0.791
AST(U/L)	15.00(7.00–42.00)	16.00(8.00–28.00)	18.00(6.00–53.00)	15.00(8.00–26.00)	4.36	0.225
ALT(U/L)	14.00(6.00–66.00)	12.00(4.00–29.00)	12.00(1.00–85.00)	13.00(6.00–42.00)	1.48	0.687
Total bilirubin(μmol/L)	4.80(1.10–11.00)	5.25(1.00–10.80)	4.60(0.80–12.00)	4.10(0.60–15.20)	1.69	0.640
CO2-CP(mmol/L)	25.70(19.20–31.70)	26.45(5.20–33.60)	25.40(10.60–31.30)	25.60(6.50–35.60)	1.75	0.627
Urea(mmol/L)	20.10(8.78–34.76)	18.55(8.77–28.24)	15.83(8.17–37.52)	16.34(5.61–28.65)	6.88	0.076
Uric acid (μmol/L)	406.57. ±86.47	381.90±83.70	406.95±91.85	433.19±80.11	2.30	0.079
Creatinine (μmol/L)	1184.00(714.00–1724.00)	1013.00(633.00–1736.00)	826.00(398.00–1738.00)	813.00(423.00–1623.00)	31.64	<0.001
24h urine volume(mL)	0.03(0.00–400.00)	400.00(150.00–1100.00)	860.00(350.00–1700.00)	1100.00(50.00–2400.00)	110.71	<0.001

[a] classified into four groups based on quartiles of residual GFR.

[b] Comparisons were made by one-way ANOVA or Kruskal-Wallis H test for continuous variables while Cochran-Mantel-Haenszel χ^2test for categorical variables.

doi:10.1371/journal.pone.0156423.t002

Table 4 showed that residual GFR levels increased with nPCR rising. The medians of residual GFR were 0.70, 0.57, 2.37, and 2.24 mL/min per 1.73m^2 in nPCR quartiles (*P* for trend <0.0001). And similar results were noted in serum Cl^- (*P* <0.0001), and 24 hours urine volume (*P* <0.0001). There was a drop tendency of residual GFR with the increase of serum P^{3-} (*P* for trend less than 0.001), Mg^{2+} (*P* = 0.025) and creatinine (*P* <0.0001), respectively.

Table 3. The odds ratio of RRF loss associated with nutritional markers and biochemical parameters.

Variables	OR(95%CI)[a]	Ward χ2	*P*
BSA(m^2)			
Q1 (1.21–1.47)	0.55(0.20–1.51)	1.33	0.248
Q2 (1.47–1.60)	1		
Q3 (1.60–1.73)	1.14(0.44–2.99)	0.07	0.785
Q4 (1.73–2.02)	0.57(0.20–1.64)	1.09	0.296
nPCR(mg/kg.d)			
Q1 (10.33–28.79)	1.06(0.42–2.70)	0.02	0.899
Q2 (28.79–33.24)	1		
Q3 (33.24–38.98)	0.24(0.09–0.65)	7.99	0.005
Q4 (38.98–83.09)	0.11(0.03–0.35)	13.76	<0.001
P^{3-}(mmol/L)			
Q1 (0.46–1.30)	0.69(0.24–2.01)	0.46	0.499
Q2 (1.30–1.66)	1		
Q3 (1.66–2.11)	2.67(1.03–6.92)	4.07	0.044
Q4 (2.11–3.40)	3.45(1.35–9.04)	6.61	0.010
Na^+(mmol/L)			
Q1 (125.60–137.40)	2.32(0.92–5.89)	3.16	0.076
Q2 (137.40–139.40)	1		
Q3 (139.40–141.00)	0.98(0.38–2.51)	0.01	0.960
Q4 (141.00–148.40)	0.55(0.21–1.44)	1.46	0.227
Cl^-(mmol/L)			
Q1 (81.90–93.90)	5.34(1.94–14.68)	10.55	0.001
Q2 (93.90–96.40)	1		
Q3 (96.40–99.30)	0.82(0.32–2.08)	0.18	0.671
Q4 (99.30–135.80)	0.28(0.09–0.85)	5.03	0.025
Mg^{2+}(mmol/L)			
Q1 (0.62–0.79)	1.55(0.58–4.16)	0.77	0.381
Q2 (0.79–0.89)	1		
Q3 (0.89–1.01)	2.49(0.94–6.56)	3.39	0.066
Q4 (1.01–1.31)	3.77(1.48–3.63)	7.70	0.006
Creatinine(μmol/L)			
Q1 (398.00–795.00)	0.35(0.10–1.18)	2.87	0.090
Q2 (795.00–963.00)	1		
Q3 (963.00–1214.00)	2.93(1.09–7.88)	4.56	0.033
Q4 (1214.00–1738.00)	8.64(2.79–26.78)	13.95	<0.001
24h urine volume(mL)			
Q1 (0.00–200.00)	22.87(2.76–189.24)	8.42	0.004
Q2 (200.00–550.00)	1		
Q3 (550.00–1000.00)	0.08(0.02–0.28)	15.82	<0.001
Q4 (1000.00–2400.00)	–	0.01	0.940

[a] age and sex were adjusted in the logistic regression model for each of the variables.

doi:10.1371/journal.pone.0156423.t003

Table 4. The trend of the relationship between residual renal function and biochemical parameters.

Variables	residual GFR (median)[a]				*P*
	Q1(0–25%)	Q2(25%-50%)	Q3(50%-75%)	Q4(75%-100%)	
nPCR	0.70	0.57	2.37	2.24	<0.001
P^{3-}	2.46	1.97	0.91	0.57	<0.001
Cl^{-}	0.48	1.39	1.70	3.66	<0.001
Mg^{2+}	2.06	1.92	1.23	0.49	0.025
creatinine	2.78	1.74	1.07	0.48	<0.001
24h urine volume	0.00	0.77	2.30	3.35	<0.001

[a] the median of residual GFR among groups classified by the interquartile range of biochemical parameters.

doi:10.1371/journal.pone.0156423.t004

Discussion

As an important prognostic factor for PD patients, higher RRF is better for disease progression. Preserving RRF therefore became a key target in the treatment of CAPD patients. The present study showed a significant correlation between the fall in RRF and the increase in serum P^{3-}(OR_{Q3} = 2.67, 95%CI: 1.03–6.92; OR_{Q4} = 3.45, 95%CI: 1.35–9.04), Mg^{2+} (OR_{Q4} = 3.77, 95%CI: 1.48–3.63), and creatinine (OR_{Q3} = 2.93, 95%CI: 1.09–7.88; OR_{Q4} = 8.64 95%CI: 2.79–26.78), while positively associated with nPCR (OR_{Q3} = 0.24, 95%CI: 0.09–0.65; OR_{Q4} = 0.11, 95%CI: 0.03–0.35), 24 hours urine volume(OR_{Q1} = 22.87, 95%CI: 2.76–189.24; OR_{Q3} = 0.08, 95%CI: 0.02–0.28) and serum Cl^{-} (OR_{Q1} = 5.34, 95%CI: 1.94–14.68; OR_{Q4} = 0.28, 95%CI: 0.09–0.85), respectively.

The positive relationship between RRF and 24h urine volume may due to the fact that residual renal contributed to urinary formation and micturition excretory. And the higher risk of RRF deterioration induced by increased serum creatinine and Mg^{2+} may result from the fact that loss of RRF would contributed to excretory impairment of body fluid and eleclxolytes.

Abnormal calcium-phosphate metabolism such as hyperphosphatemia is a frequent complication in PD patients as it is in HD patients. According to the NECOSAD study, around 40% of the long-term PD patients had serum phosphorus level above the Kidney Disease Outcome Quality Initiative (K/DOQI) target (1.78 mmol/L) [25]. RRF is one of the key determinants of phosphate control in PD patients and its importance outweighs that of the PD clearance among those with preserved RRF [26, 27]. It has been reported that a significantly lower phosphate correlated with a higher RRF, and the RRF in PD patients contributes significantly to the maintenance of phosphate balance and may explain the lower prevalence of cardiac valve calcification (CVC) in PD patients [28]. Cardiac valve calcification has long been regarded as a consequence of abnormal calcium-phosphate metabolism, which was an important complication in dialysis patients and was largely attributed to abnormally increased calcium and phosphorus product. The poor phosphorus control together with the greater inflammatory response in anuric peritoneal dialysis patients translated to a greater calcification risk profile and thus predisposed to a higher incidence of valvular calcification [27].

The relationship between RRF and serum chlorine level should be evaluated with caution. In consideration of the fact that patients with ESRD tended to be educated to limit salt intake in our hospital, we can't rule out the possibility that patients with little residual GFR restricted chlorine salt intake more severely. In addition, residual GFR loss would lead to more serious fluid overload, which need to remove much more water and molecules by dialysis, including chlorine, to maintain fluid homeostasis than patients with relative high renal GFR.

Normalized protein catabolic rate (nPCR) is considered a nutritional marker for nitrogen intake and a useful measure to evaluate dietary protein intake in patients with ESRD. Its

increase can be obtained by means of intra-dialytic parenteral nutrition [29–31]. It has been reported that nPCR correlated well with RRF, a significant reduction of nPCR occurs in progressive renal perfusion insufficiency, and may predict the need for dialysis treatment. It has been reported that the level of nPCR less than 0.8 at initiation predicted future lower nPCR levels and mortality on dialysis [32, 33]. The underlying mechanisms for positive relationship between nPCR levels and residual GFR were that low nPCR levels predicted weight loss and protein calorie malnutrition, which were predictors of morbidity and mortality for patients with chronic renal failure and CAPD [34–36]. Another genuine physiological association was that reduced renal function leaded to insufficient protein intake and decreased nPCR level. In addition, it has been reported that nPCR was positively correlated with normalized models of dialysis adequacy including KT/V (urea), total weekly creatinine clearance and the dialysis index [33, 37].

The present study also has some limitations. First, the number of patients was relatively small. Second, it was an exploratory study of the association between nutritional markers and biochemical parameters and residual GFR. Finally, although the univariate logistic regression analysis performed in this study indicated that serum P^{3-}, Ca^{2+}, Cl^{-}, Mg^{2+}, creatinine, nPCR levels and the 24 hours urine volume as independent factors for the residual GFR, which could not exclude the impact of interactions among these variables. Accordingly, the results of this study should be confirmed by large-scale prospective and more rigorous studies.

Overall, the present study demonstrated that serum P^{3-}, Cl^{-}, Mg^{2+}, creatinine and the 24 hours urine volume were significantly associated with residual GFR. As an important nutritional marker, the nPCR level may serve as a valuable preditor of residual renal function loss.

Supporting Information

S1 Appendix. STROBE checklist—checklist of items that should be included in reports of observational studies.
(DOCX)

S2 Appendix. The data set of demographic characteristics, nutritional markers and biochemical parameters of the 155 participants.
(XLSX)

Author Contributions

Conceived and designed the experiments: LL YY ZM. Performed the experiments: LL WL TY ZC ZZ XD KQ XZ XH CZ. Analyzed the data: LL YY JL LW. Contributed reagents/materials/analysis tools: YY JL WL. Wrote the paper: LL YY TY.

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