ORIGINAL

Excessive dietary phosphorus intake impairs endothelial function in young healthy men : a time- and dose-dependent study

Tamae Nishi[1,4*], Emi Shuto[2*], Mariko Ogawa[2], Miho Ohya[2], Misaki Nakanishi[2], Masashi Masuda[1], Misaki Katsumoto[1], Hisami Yamanaka-Okumura[1], Tohru Sakai[2], Eiji Takeda[1], Hiroshi Sakaue[3], and Yutaka Taketani[1]

[1]*Department of Clinical Nutrition and Food Management,* [2]*Department of Applied Nutrition, and* [3]*Department of Nutrition and Metabolism, Institute of Health Biosciences, University of Tokushima Graduate School, Tokushima, Japan,* [4]*Department of Gastroenterology, Hepatology and Nutrition, Kurashiki Medical Center, Kurashiki, Japan*

Abstract : Excessive dietary phosphorus (P) has been speculated to be a risk factor for cardiovascular disease (CVD). Here, we performed a double-blinded crossover study to investigate the time- and dose-dependent effects of dietary P intake on endothelial function in healthy subjects. Sixteen healthy male volunteers were given meals containing 400, 800, and 1,200 mg P (P400, P800, and P1200 meals, respectively) with at least 7 days between doses. There were no differences in nutritional composition among the experimental diets except for P content. Blood biochemistry data and flow-mediated dilation (%FMD) of the brachial artery were measured while fasted, at 0 h, 1 h, 2 h, and 4 h after meal ingestion, and the next morning while fasted. The P800 and P1200 meals significantly increased serum P levels at 1-4 h after ingestion. A significant decrease in %FMD was observed between 1-4 h, while the P400 meal did not affect %FMD. We observed no differences among meals in serum P levels or %FMD the next morning. A significant negative correlation was observed between %FMD and serum P. These results indicate that excessive dietary P intake can acutely impair endothelial function in healthy people. J. Med. Invest. 62 : 167-172, August, 2015

Keywords **:** *phosphorus, endothelial dysfunction, flow-mediated vasodilation, hyperphosphatemia, chronic kidney disease*

INTRODUCTION

Cardiovascular disease (CVD) is the most important complication contributing to reduced life expectancy in patients with chronic kidney disease (CKD) (1-3). Traditional and non-traditional risk factors relating to the pathogenesis of CVD in CKD patients have been identified (4, 5). Hyperphosphatemia has recently been recognized as a mediator between CKD and CVD (6, 7). Hyperphosphatemia is also an emerging problem, not only in CKD patients, but also in the healthy population. Recent studies have demonstrated that higher serum P levels, even those within the normal range, were associated with the development of atherosclerosis and mortality in the population with normal kidney function (8) and in the Framingham Offspring Study participants (9). Onufrak *et al.* also demonstrated that a high serum P level was associated with thickening of the carotid artery intima media in the general population (10). Hyperphosphatemia can induce the differentiation of vascular smooth muscle cells to osteoblast-like cells that are involved in the medial calcification of the artery, so-called Mönkeberg's arteriosclerosis (11-13). In addition, we and others have demonstrated that hyperphosphatemia can also mediate endothelial dysfunction (14-16), which is a principal cause of atherosclerosis resulting in CVD.

Our previous study demonstrated that the ingestion of a high P diet (1,200 mg P per meal) impaired flow-mediated dilation at 2 h after meal ingestion in young healthy men, compared with those given a control diet (400 mg P per meal) (14). In addition, increasing the extracellular P level induced increased oxidative stress and decreased nitric oxide production in bovine thoracic aorta endothelial cells (14). Peng *et al.* reported that hyperphosphatemia decreased endothelial nitric oxide synthase (eNOS) expression in human umbilical vein endothelial cells (15). DiMarco *et al.* also demonstrated that an elevation of extracellular P can induce apoptosis via increased oxidative stress in human endothelial cell lines (16). These results suggest that over a high dietary intake of P may contribute to the pathogenesis of CVD. In this study, we performed a double-blinded crossover study to investigate the dose- and time-dependent effects of high dietary P intake on endothelial function in healthy human subjects.

METHODS

Subjects

Sixteen male volunteers aged 23.4±2.8 years and without apparent health problems were recruited for this study. The participants showed no evidence of diabetes, abnormal glucose intolerance, obesity, hypertension, kidney diseases, CVD, dyslipidemia, or other bone and mineral disorders. Demographic data for the participants are provided in Table 1. All participants were nonsmokers, had normal blood pressure, consumed < 30 g/d alcohol, and took no medications or antioxidant supplements. The eligibility of participants for this study was determined similarly to our previous reports (14, 17).

Study design

The study used a double-blinded crossover design, with the administration of meals containing specific amounts of P to each volunteer on 3 different days, each separated from the other test days by more than 1 week. Figure 1 illustrates the design of the study.

*These authors contributed equally to this work.

Received for publication February 3, 2015 ; accepted February 17, 2015.

Address correspondence and reprint requests to Yutaka Taketani, Ph. D, Professor, Department of Clinical Nutrition and Food Management Institute of Health Biosciences, University of Tokushima Graduate School 3-18-15, Kuramoto-cho, Tokushima 770-8503, Japan and Fax : +81-88-633-7094.

Table 1. Baseline characteristics of subjects.

Age	23.4±2.8
Height (cm)	171.5±2.8
Weight (kg)	60.4±5.1
Percentage body fat (%)	14.2±7.0
Body fat (kg)	8.8±3.5
Fat free mass (kg)	51.6±4.5
Muscle mass (kg)	48.9±4.3
Total body water (kg)	35.0±3.4
BMI (kg/m^2)	20.5±2.1

Values are mean±S.E.M., n=16.

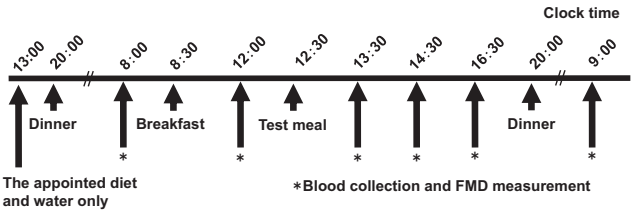

Figure 1. Study schema. The three test meals containing different amounts of P were served at 12 : 30 on the test day. The subjects were allowed only the standardized water and meals that we supplied after 14 : 00 on the day before the test day. Asterisks indicate the times at which blood collection and FMD measurements were performed.

On the day before each test day, the subjects were asked to abstain from foods and beverages other than water not containing P after 13 : 00. They were served a standard dinner at 20 : 00 on the evening before each test day, and a standard breakfast at 8 : 30 on each test day. On the test days, subjects were served either a P400 meal (standard lunch, which contained 400 mg of P+placebo supplement (NaCl)), a P800 meal (standard lunch+400 mg neutralized phosphate supplement), or a P1200 meal (standard lunch+800 mg neutralized phosphate supplement) for lunch at 12 : 30. The composition of the test meals and standard dinner and breakfast is provided in our previous study. In brief, the standard dinner consisted of 700 kcal in energy with a protein : fat : carbohydrate ratio in %energy of 15 : 19 : 66, and contained 200 mg of calcium (Ca) and 400 mg of P. The standard breakfast consisted of 700 kcal with a protein : fat : carbohydrate ratio in %energy of 14 : 21 : 65, and contained 200 mg of Ca and 400 mg of P. Standard lunch consisted of 700 kcal with a protein : fat : carbohydrate ratio in %energy of 14 : 21 : 65, and contained 200 mg of Ca and 400 mg of P.

We collected blood samples immediately before (0 h), and at 1 h, 2 h, 4 h, and 20 h after the test meal ingestion. Venous blood was taken from a median cubital vein for the measurement of serum glucose, insulin, P, Ca, Na, K, Cl, intact-PTH (iPTH) and high sensitivity-C reactive protein (hs-CRP) concentrations. All biochemical measurements and analyses were performed by LSI Medience (Tokyo, Japan). Serum monocyte-chemoattractant protein (MCP-1) and fibroblast growth factor 23 (FGF23) were measured by CCL2/MCP-1 immunoassay kit (R&D Systems Inc., Minneapolis, MN) and FGF23 ELISA kit (Kinos, Tokyo, Japan), respectively. We also measured blood pressure and flow-mediated dilation (FMD) by using UNEXEF 18G (UNEX Corporation, Aichi, Japan) according to previously published guidelines (18) immediately before (0 h), and at 1 h, 2 h, 4 h, and 20 h after the test meal ingestion.

The study protocols were approved by the Ethics Committee of the Tokushima University Hospital. This study has been registered and opened on the UMIN-CTR database in Japan according to the ICMJE guidelines (UMIN000000803, Dietary phosphorus loading trial in human).

Statistical analysis

We tested all data for normal distribution of variables of interests by Kolmogorov-Smirnov test before further parametric or nonparametric statistical analysis. If the test judged the data to be normally distributed, we performed subsequent statistical analysis by parametric analysis. If not, we used nonparametric analysis.

Serum biochemical measurements and %FMD within groups and the effects of meals on pre-prandial and post-prandial values of these measurements were analyzed by repeated measurements analysis of variance (ANOVA) and post hoc analysis by Bonferroni's method.

For the association analysis, we performed a simple regression analysis and estimated Spearman's non-parametric correlation coefficients. We selected the nonparametric procedure, which does not require normally distributed data or linear associations of the variables of interest.

We performed all statistical analyses using SPSS Statistics 17.0.

RESULTS

1. Dose and time-dependent effects of high dietary P intake on the serum P level and other P metabolism-regulating factors

In this study, the subjects alternately received P400, P800, or P1200 meals as lunch and the serum levels of P and P metabolism-regulating factors were measured in the morning (fasting), and before and after intake of the test meal (Table 2 and 3). In spite of the differences in P content among the test meals, the serum P level was significantly increased at 1 h, 2 h, and 4 h after the ingestion of the test meals, compared with the pre-prandial serum P level. However, the serum P levels at 1 h, 2 h, and 4 h after ingestion of the P1200 meal were significantly higher than that measured following ingestion of the P400 meal (Figure 2). Area under the curve (AUC) analysis revealed post-prandial changes in the serum P level during the 4 h after test meal ingestion ; the serum P level was increased accordingly with the increases in phosphorus intake (Figure 3A). In addition, the serum P levels were above the normal range at 1 h, 2 h, and 4 h after ingestion of the P800 or P1200 meals, but not after ingestion of the P400 meal. Serum P levels had reverted to a normal level when measured the next morning after ingestion of the test meals.

Serum intact-PTH levels did not show significant differences among the groups ; however, they showed a biphasic peak at 1 h and 4 h after ingestion of the test meals (Table 2), as reported previously (17). The intact-PTH level at 4 h after ingestion of the P400 and P1200 meals was significantly increased compared with the pre-prandial serum intact-PTH level. The AUC for post-prandial serum intact-PTH changes over 4 h increased accordingly with the increases in the intake of P (Figure 3B). The AUC after the ingestion of the P1200 meal was significantly greater than that after the P400 meal ($P< 0.05$). FGF23 is also an important P metabolism-regulating hormone. The serum FGF23 level was not increased following ingestion of the test meals (Table 3). Serum Na, K, Cl, Ca, hs-CRP, and MCP-1 levels also were not affected by the experimental increases in P intake (Tables 2 and 3).

2. Dose- and time-dependent effects of high dietary P intake on FMD

We demonstrated that intake of the P1200 meal led to a significant decrease in %FMD compared with that measured following intake of the P400 meal at 2 h after meal ingestion (14). Here, we investigated the dose- and time-dependent effects of high dietary

Table 2. Measurements of blood and urine biochemical markers.

		%FMD	SBP (mmHg)	DBP (mmHg)	Glucose (mg/dL)	Insulin (μU/mL)	Na (mEq/L)	K (mEq/L)	Cl (mEq/L)	Ca (mEq/L)	P (mEq/L)	Intact-PTH (pg/dL)
	Normal Range		<130	<85	70-109	1.7-10.4	137-147	3.5-5.0	98-108	8.4-10.4	2.5-4.5	10-65
P400 meal	Morning	10.6±0.4	117±2.1	70.3±2.1	91.9±2.2	3.93±0.5	141±0.3	4.10±0.1	103±0.5	9.89±0.1	4.02±0.1	41.0±2.9
	Pre-prandial	11.1±0.3	114±2.5	65.9±2.6	83.4±2.4	4.90±0.7	140±0.4	4.31±0.1	103±0.4	9.90±0.1	3.82±0.1	31.9±2.6
	1 H	10.2±0.2	116±2.6	63.1±2.1	96.9±3.9	16.5±1.7*	142±0.5	4.04±0.1*	104±0.5	9.65±0.1	4.13±0.1*	33.7±2.1
	2 H	9.25±0.3	115±2.4	64.1±1.8	102±2.3	15.4±1.1*	141±0.5	4.08±0.1*	104±0.4	9.72±0.1	4.26±0.1*	32.4±2.2
	4 H	10.2±0.4	113±2.2	66.2±1.9	95.2±2.0	5.80±1.0	141±0.4	4.22±0.1	103±0.4	9.78±0.1	4.48±0.1*	40.7±2.5*
	Next morning	10.6±0.3	113±2.1	68.4±1.8	92.3±1.4	366±0.3	140±0.3	4.16±0.1	103±0.4	9.86±0.1	3.91±0.1	33.5±1.6
P800 meal	Morning	10.1±0.4	115±2.5	69.9±1.6	89.9±2.0	3.65±0.4	140±0.3	4.08±0.1	102±0.5	9.94±0.1	4.10±0.1	39.0±3.6
	Pre-prandial	10.8±0.2	113±2.8	65.0±2.0	82.6±2.5	6.94±2.0	140±0.4	4.38±0.1	103±0.3	9.84±0.1	3.81±0.1	33.1±2.5
	1 H	6.65±0.4*	115±2.5	63.8±1.5	95.9±4.1	16.7±1.6*	141±0.5*	4.08±0.1*	103±0.3	9.59±0.1	4.81±0.1*	39.6±2.1
	2 H	5.89±0.5*	113±2.4	62.5±1.8	101±3.9	15.6±1.7*	141±0.4*	4.08±0.1*	102±0.4	9.63±0.1	4.89±0.1*	38.1±2.0
	4 H	7.21±0.4*	115±2.3	67.4±1.5	92.1±2.2	4.46±0.4	140±0.3	4.14±0.1	102±0.4	9.71±0.1	4.86±0.1*	39.6±3.3
	Next morning	10.5±0.4	113±2.6	67.3±2.0	91.5±1.5	3.58±0.3	140±0.3	4.22±0.1	102±0.4	9.93±0.1	3.89±0.1	34.7±3.4
P1200 meal	Morning	9.99±0.3	117±2.2	70.3±1.8	90.9±2.0	3.79±0.4	140±0.5	4.14±0.1	102±0.5	9.85±0.1	4.00±0.1	40.8±3.3
	Pre-prandial	10.6±0.3	116±2.6	66.9±2.1	81.1±2.9	5.10±0.9	140±0.5	4.31±0.1	103±0.3	9.89±0.1	3.75±0.1	33.6±2.7
	1 H	5.28±0.4*	115±2.4	63.1±1.8	102±4.6	21.2±2.6*	141±0.5*	3.99±0.1*	103±0.4	9.59±0.1*	5.02±0.2*	41.7±2.5
	2 H	5.62±0.4*	116±2.4	64.9±1.7	97.1±3.3	14.1±1.0*	141±0.5*	4.01±0.1*	103±0.4	9.54±0.1*	5.26±0.2*	41.2±2.3
	4 H	7.06±0.4*	115±2.2	67.4±1.9	93.3±2.4	4.59±0.5	141±0.4	3.98±0.1*	102±0.3	9.66±0.1	5.23±0.1*	45.9±2.7*
	Next morning	10.6±0.3	116±2.4	67.3±1.4	91.6±1.7	3.83±0.4	141±0.4	4.11±0.1	103±0.3	9.81±0.1	3.93±0.1	32.5±2.1

P400, P400 meal ; P800, P800 meal ; P1200, P1200 meal ; %FMD, %flow-mediated dilation ; SBP, systolic blood pressure ; DBP, diastolic blood pressure ; Cre, creatinine. Values are mean±S.E.M. for 16 subjects. $P<0.05$ vs pre-prandial in the same meal.

Table 3. Effects of high dietary phosphorus intake on serum hs-CRP, MCP-1, and FGF23 levels.

		Pre-prandial	4 h	Next morning
P400 meal	hs-CRP (mg/dL)	0.035±0.0	0.034±0.0	0.029±0.0
	MCP-1 (pg/dL)	165.8±7.2	164.3±6.5	166.2±6.1
	FGF23 (pg/mL)	41.6±16.5	35.7±16.7	45.0±15.5
P800 meal	hs-CRP (mg/dL)	0.048±0.0	0.043±0.0	0.035±0.0
	MCP-1 (pg/dL)	165.7±6.7	157.2±6.8	160.9±5.9
	FGF23 (pg/mL)	50.8±13.5	39.3±15.6	40.7±14.7
P1200 meal	hs-CRP (mg/dL)	0.062±0.0	0.061±0.0	0.052±0.0
	MCP-1 (pg/dL)	165.8±8.3	154.7±7.8	160.9±7.7
	FGF23 (pg/mL)	60.6±16.7	40.1±16.2	49.2±18.4

Abbreviations are hs-CRP, high sensitive-C reactive protein ; MCP-1, monocyte/macrophage chemoattractant protein-1 ; FGF23, fibroblast growth factor 23.

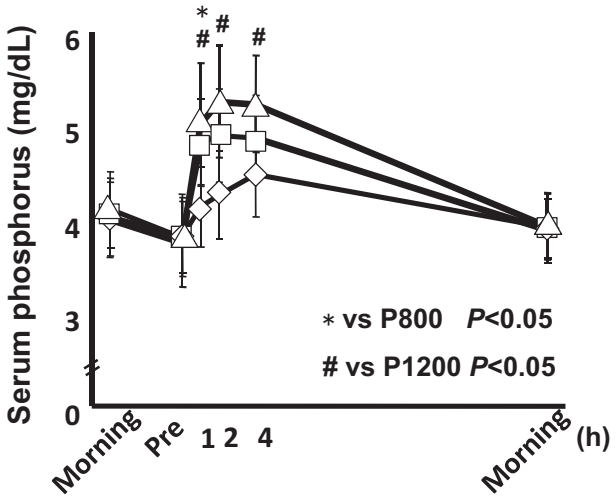

Figure 2. Effects of high dietary P intake (open diamond, P400 meal ; open square, P800 meal ; open triangle, P1200 meal) on the serum P level before and after ingestion of test meals. Data are mean±S.E.M. for 16 subjects.

P intake on FMD in young healthy men. As shown in the Figure 4, %FMD at 1 h, 2 h, and 4 h after the ingestion of P800 and P1200 meals was significantly decreased compared with that measured following ingestion of the P400 meal. The peak inhibition of FMD by P800 was observed at 2 h after meal ingestion, while that by P 1200 was at 1 h after meal ingestion. In addition, the decrease in %FMD observed after high P intake was recovered by the next morning. The rate of increase in the post-prandial serum P level between 0-4 h after meal intake was significantly correlated with the rate of decrease in %FMD (Figure 5).

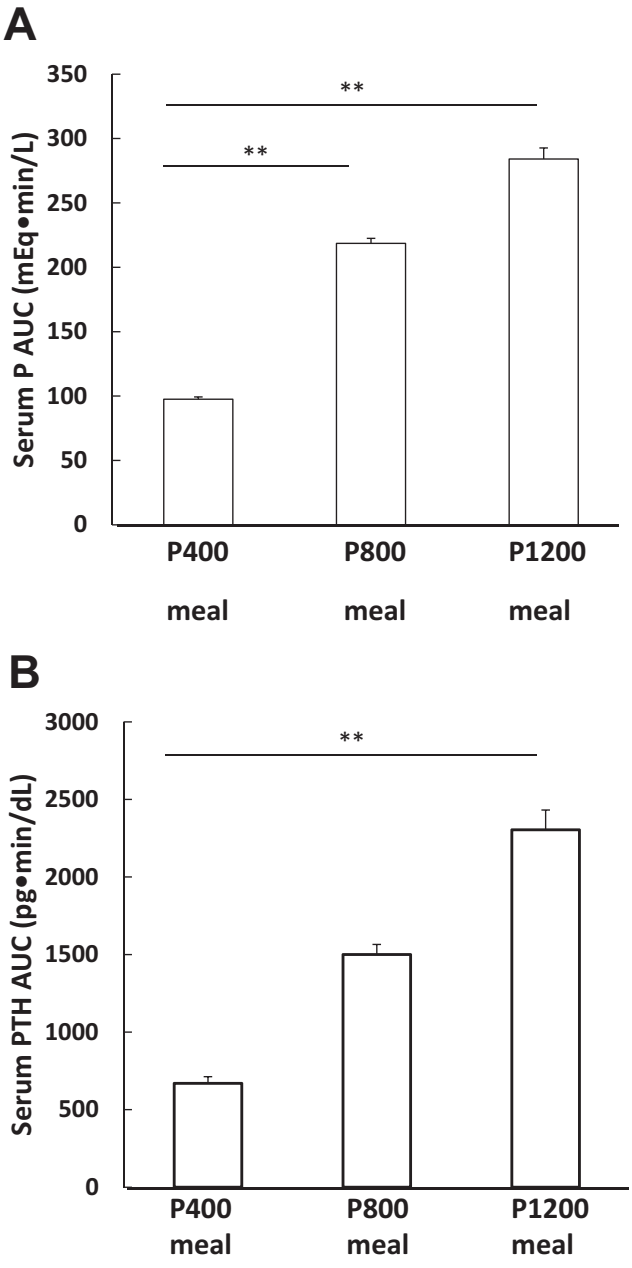

Figure 3. Effects of high dietary P intake on areas under the curve for post-prandial changes in serum P (A) and intact PTH levels (B) over 4 h after ingestion of the test meal. Data are mean±S.E.M. for 16 subjects. $^{**}P < 0.01$ for differences among the meals.

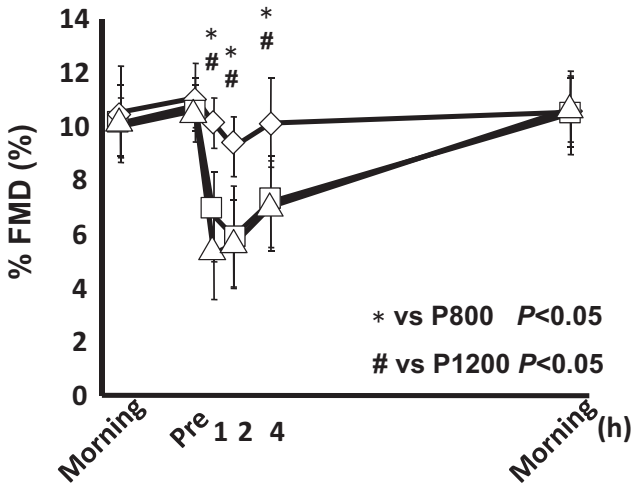

Figure 4. Effects of high dietary P intake (open diamond, P400 meal ; open square, P800 meal ; open triangle, P1200 meal) on %FMD (B) before and after ingestion of test meals. Data are mean±S.E.M. for 16 subjects.

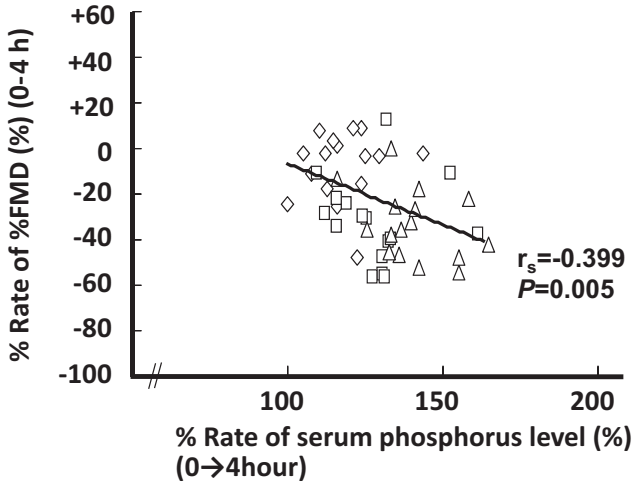

Figure 5. Univariate association analysis of the ratios of changes (%) in serum P and %FMD from pre-prandial measurements to those made 4 h after ingestion of the test meals. All variables were centralized according to the median value for each individual. Each symbol is used as in Figure 2. Spearman's correlation coefficient (r_s) and its P-value for $r_s=0$ are presented in the association.

DISCUSSION

In this study, we investigated the time- and dose-dependent effects of high dietary P intake on endothelial function by evaluating %FMD. We found that FMD was rapidly inhibited by high P intake, but began to be recovered at 4 h and was normalized by the next morning. We did not find any clear differences between the P800 and P1200 meals in the high dietary P intake-induced inhibition of FMD. However, the P1200 meal inhibited FMD slightly faster than did the P800 diet. In addition, the inhibitory effect of high dietary P intake could be observed at the minimum level of intake of 800 mg of phosphorus in a single meal.

The post-prandial increase in the serum P level was significantly

correlated with the degree of impairment of FMD. Our previous work demonstrated that the experimental elevation of the extracellular P level can inhibit nitric oxide production in endothelial cells via increasing oxidative stress and the inhibitory phosphorylation of eNOS (14). Therefore, a transient increase in the serum P level may be enough to lead to a deterioration of endothelial function. Another possible mechanism for the impairment of endothelial function by a high serum P level is via PTH and FGF23. The post-prandial serum PTH level was increased by high dietary P intake in a dose-dependent manner. Primary hyperparathyroidism patients have an impaired FMD (19-22), but the impairment of FMD was ameliorated after parathyroidectomy (21, 20). Parathyroidectomy or Ca channel blockade was reported to restore inhibited eNOS activity in a rat model of CKD (23). On the other hand, FGF23 also can directly impair endothelium-dependent vasodilation by increasing oxidative stress and reducing NO availability (24). However, the serum FGF23 level was not increased after a single ingestion of a high P meal in our study. Thus, the serum FGF23 level did not appear to be related to the decreases in %FMD observed in this study.

A transient increase in the serum P level may be an important atherogenic factor. Watari *et al.* demonstrated that inducing fluctuations in the serum P level by the alternating administration of high or low P diets led to a deterioration of endothelium-dependent vasodilation and an increased expression of VCAM-1 and MCP-1 in the tunica intima (25). The impairment of endothelial function by the alternating administration of high or low P diets was almost same as that produced by the chronic administration of a high P diet (25). Therefore, repeated transient increases in the serum P level may have some of the same adverse effects on endothelial cells as continuous high dietary P intake.

A chronic increase in the serum P level is a well-known risk factor for CVD, not only in CKD patients, but also in the general population (6, 10). In addition, Yamamoto *et al.* reported that a high dietary P intake was associated with left ventricular hypertrophy (26). They concluded that the highest quintile of dietary phosphorus intake (male 1,554-5,032 mg/day, female 1,346-4,069 mg/day) was associated with an greater left ventricular hypertrophy compared with the lowest quintile (male 270-687 mg/day, female 251-585 mg/day). A recent study demonstrated that high dietary P intake was associated with all-cause mortality in the NHANES III cohort (27). All-cause mortality was significantly increased in the people with high phosphorus intake (more than 1,400 mg/day) compared with low phosphorus intake (less than 1,400 mg/day). In our study, standard P400 meal corresponded to 1,200 mg of daily phosphorus consumption if the subject consumed the same meal three times per day. On the other hand, the ingestion of P800 or P1200 meal three times per day would be estimated over 1,400 mg/day. In this study, the single-time ingestion of P800 or P1200 meal significantly deteriorated endothelial function. Therefore, habitual consumption of high phosphorus diet likes P800 and P1200 meals may increase the risk of cardiovascular disease.

High phosphorus diet also causes large fluctuation of serum phosphorus levels. Portale *et al.* demonstrated that there is a circadian rhythm of the serum P level (28), with the serum P level being at its lowest during the morning fasting state and highest during the night. A high dietary intake of P increased the serum P level during both day and night, except during the morning fasting state. Thus, a chronic high phosphorus diet can widen the amount of difference between the lowest and highest serum P levels present during each circadian cycle. Such large daily fluctuations arising from continuous high dietary P intake may cause endothelial dysfunction in humans, as was previously observed in rodents (25).

This study has some limitations. Firstly, this study was carried out with a limited number, gender, and age range of subjects, although the impact of these limitations was reduced by the use of a double-blinded crossover protocol. A further intervention study with a large number of subjects of different ages and genders should be performed to confirm our results in the future. Secondly, we could not fully clarify the effects of FGF23, PTH, or other factors on endothelial dysfunction caused by high dietary P intake. An elevation or fluctuations in the serum P level must directly inhibit endothelial function. However, PTH and FGF23 may be important as mediators of the deterioration of endothelial function produced by chronic high dietary P intake. Thus, a study investigating the effects of the chronic administration of a high P diet is needed to clarify the effects of PTH or FGF23 on the impairment of endothelial function.

In conclusion, excessive dietary P intake can acutely impair endothelial function in healthy people. Habitual excessive P intake and the resulting endothelial dysfunction may contribute to the progression of CVD or increased mortality, as is suggested by epidemiological data.

ACKNOWLEDGEMENTS

This work was supported by Grants-in-aid for Scientific Research (B) (22300237) from the Japan Society for the promotion of Science (JSPS) and the kidney foundation (JKFB08-22).

CONFLICT OF INTEREST

We have no conflicts of interest to declare for this study.

DISCLOSURE

No conflicts of interest are declared.

REFERENCES

1. Levin A : Clinical epidemiology of cardiovascular disease in chronic kidney disease prior to dialysis. Semin Dial 16 : 101-105, 2003
2. Kendric J, Chonchol M : Cardiovascular disease in CKD in 2013 : Reducing cardiovascular risk-light at the end of the tunnel. Nat Rev Nephrol 10 : 71-72, 2014
3. Afsar B, Turkmen K, Covic A, Kanbay M : An update on coronary artery disease and chronic kidney disease. Int J Nephrol 2014 : 767424. doi : 10.1155/2014/767424, 2014
4. Zoccali C, Mallamaci F, Tripepi G : Novel cardiovascular risk factors in end-stage renal disease. J Am Soc Nephrol 15 : S77-S80, 2004
5. Stenvinkel P, Carrero JJ, Axelsson J, Lindholm B, Heimbürger O, Massy Z : Emerging biomarkers for evaluating cardiovascular risk in the chronic kidney disease patient : how do new pieces fit into the uremic puzzle? Clin J Am Soc Nephrol 3 : 505-521, 2008
6. Kanbay M, Goldsmith D, Akcay A, Covic A : Phosphate-the silent stealthy cardiorenal culprit in all stages of chronic kidney disease : a systematic review. Blood Purif 27 : 220-230, 2009
7. Gupta D, Brietzke S, Hayden MR, Kurukulasuriya LR, Sowers JR : Phosphate metabolism in cardiorenal metabolic disease. Cardiorenal Med 1 : 261-270, 2011
8. Tonelli M, Sacks F, Pfeffer M, Gao Z, Curhan G : Relation between serum phosphate level and cardiovascular event rate in people with coronary disease. Circulation 112 : 2627-2633, 2005

9. Dhingra R, Sullivan LM, Fox CS, Wang TJ, D'Agostino RB Sr, Gaziano JM, Vasan RS : Relations of serum phosphorus and calcium levels to the incidence of cardiovascular disease in the community. Arch Intern Med 167 : 879-885, 2007
10. Onufrak SJ, Bellasi A, Shaw LJ, Herzog CA, Cardarelli F, Wilson PW, Vaccarino V, Raggi P : Phosphorus levels are associated with subclinical atherosclerosis in the general population. Atherosclerosis 199 : 424-431, 2008
11. Jono S, McKee MD, Murry CE, Shioi A, Nishizawa Y, Mori K, Morii H, Giachelli CM : Phosphate regulation of vascular smooth muscle cell calcification. Cir Res 87 : E10-E17, 2000
12. Giachelli CM : Vascular calcification : in vitro evidence for the role of inorganic phosphate. J Am Soc Nephrol 14 : S300-S304, 2003
13. Moe SM, Chen NX : Pathophysiology of vascular calcification in chronic kidney disease. Circ Res 95 : 560-567, 2004
14. Shuto E, Taketani Y, Tanaka R, Harada N, Isshiki M, Sato M, Nashiki K, Amo K, Yamamoto H, Higashi Y, Nakaya Y, Takeda E : Dietary phosphorus acutely impairs endothelial function. J Am Soc Nephrol 20 : 1504-1512, 2009
15. Peng A, Wu T, Zeng C, Rakheja D, Zhu J, Ye T, Hutcheson J, Vaziri ND, Liu Z, Mohan C, Zhou XJ : Adverse effects of simulated hyper- and hypo-phosphatemia on endothelial cell function and viability. PLoS One 6 : e23268. doi : 10.1371/journal.pone.0023268, 2011
16. Di Marco GS, Hausberg M, Hillebrand U, Rustemeyer P, Wittkowski W, Lang D, Pavenstädt H : Increased inorganic phosphate induces human endothelial cell apoptosis in vitro. Am J Physiol Renal Physiol 294 : F1381-1387, 2008
17. Nishida Y, Taketani Y, Yamanaka-Okumura H, Imamura F, Taniguchi A, Sato T, Shuto E, Nashiki K, Arai H, Yamamoto H, Takeda E : Acute effect of oral phosphate loading on serum fibroblast growth factor 23 levels in healthy men. Kidney Int 70 : 2141-2147, 2006
18. Corretti MC1, Anderson TJ, Benjamin EJ, Celermajer D, Charbonneau F, Creager MA, Deanfield J, Drexler H, Gerhard-Herman M, Herrington D, Vallance P, Vita J, Vogel R : Guidelines for the ultrasound assessment of endothelial-dependent flow-mediated vasodilation of the brachial artery : a report of the International Brachial Artery Reactivity Task Force. J Am Coll Cardiol 39 : 257-265, 2002
19. Kosch M, Hausberg M, Vormbrock K, Kisters K, Rahn KH, Barenbrock M : Studies on flow-mediated vasodilation and intima-media thickness of the brachial artery in patients with primary hyperparathyroidism. Am J Hypertens 13 : 759-764, 2000
20. Baykan M, Erem C, Erdoğan T, Hacıhasanoğlu A, Gedikli Ö, Kırış A, Küçükosmanoğlu M, Ersöz H, Çelik S : Impairment of flow mediated vasodilatation of brachial artery in patients with primary hyperparathyroidism. Int J Cardiovasc Imaging 23 : 323-328, 2007
21. Kosch M, Hausberg M, Vombrock K, Kisters K, Gabriels G, Rahn KH, Barenbrock M : Impaired flow-mediated vasodilation of the brachial artery in patients with primary hyperparathyroidism improves after parathyroidectomy. Cardiovasc Res 47 : 813-818, 2000
22. Carrelli A, Walker MD, Di Tullio MR, Homma S, Zhang C, McMahon DJ, Silverberg SJ : Endothelial function in mild primary hyperparathyroidism. Clin Endocrinol 78 : 204-209, 2013
23. Vaziri ND, Ni Z, Wang XQ, Oveisi F, Zhou XJ : Downregulation of nitric oxide synthase in chronic renal insufficiency : role of excess PTH. Am J Physiol Renal Physiol 274 : F642-F649, 1998
24. Silswal N, Touchberry CD, Daniel DR, McCarthy DL, Zhang S, Andresen J, Stubbs JR, Wacker MJ : FGF23 directly impairs endothelium-dependent vasorelaxation by increasing superoxide levels and reducing nitric oxide bioavailability. Am J Physiol Endocrinol Metab 307 : E426-E436, 2014
25. Watari E, Taketani Y, Kitamura T, Tanaka T, Ohminami H, Abuduli M, Harada N, Yamanaka-Okumura H, Yamamoto H, Takeda E : Fluctuating plasma phosphorus level by changes in dietary phosphorus intake induces endothelial dysfunction. J Clin Biochem Nutr 56 : 35-42, 2015
26. Yamamoto KT, Robinson-Cohen C, de Oliveira MC, Kostina A, Nettleton JA, Ix JH, Nguyen H, Eng J, Lima JA, Siscovick DS, Weiss NS, Kestenbaum B : Dietary phosphorus is associated with greater left ventricular mass. Kidney Int 83 : 707-714, 2013
27. Chang AR, Lazo M, Appel LJ, Gutiérrez OM, Grams ME : High dietary phosphorus intake is associated with all-cause mortality : results from NHANES III. Am J Clin Nutr 99 : 320-327, 2014
28. Portale AA, Halloran BP, Morris RC Jr : Dietary intake of phosphorus modulates the circadian rhythm in serum concentration of phosphorus. Implications for the renal production of 1,25-dihydroxyvitamin D. J Clin Invest 80 : 1147, 1154, 1987