

## Do Regular High Protein Diets Have Potential Health Risks on Kidney Function in Athletes?

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Excess protein and amino acid intake have been recognized as hazardous potential implications for kidney function, leading to progressive impairment of this organ. It has been suggested in the literature, without clear evidence, that high protein intake by athletes has no harmful consequences on renal function. This study investigated body-builders (BB) and other well-trained athletes (OA) with high and medium protein intake, respectively, in order to shed light on this issue. The athletes underwent a 7-day nutrition record analysis as well as blood sample and urine collection to determine the potential renal consequences of a high protein intake. The data revealed that despite higher plasma concentration of uric acid and calcium, Group BB had renal clearances of creatinine, urea, and albumin that were within the normal range. The nitrogen balance for both groups became positive when daily protein intake exceeded  $1.26 \text{ g} \cdot \text{kg}^{-1}$  but there were no correlations between protein intake and creatinine clearance, albumin excretion rate, and calcium excretion rate. To conclude, it appears that protein intake under  $2.8 \text{ g} \cdot \text{kg}^{-1}$  does not impair renal function in well-trained athletes as indicated by the measures of renal function used in this study.

*Key Words:* glomerular filtration rate, albumin excretion rate, nitrogen balance

It has been suggested that excessive protein or amino acid intake in healthy athletes may be associated with kidney problems (17, 19, 27). High protein diets produce high amounts of urea, an end-product primarily excreted via urine. It is also commonly observed that athletes are at risk for dehydration, therefore limiting urea excretion. Theoretically, high protein and amino acid intakes may place stress on the liver (obligatory oxidation) and kidneys (hyperfiltration). However, there is no published evidence that a high protein diet produces negative effects on kidney and liver metabolism in athletes. There may be excessive loss of urinary calcium with a high protein diet (8, 9, 29). Protein ingestion has increasingly been recognized as an important determinant of renal function. Diminished dietary protein intake in normal subjects has been shown to reduce glomerular filtration rate and effective renal plasma flow (2). It has been postulated that chronic protein load causes glomerulonephritis through the mechanism of hypertension (3). Indeed, several publications reported that meat consumption increases the glomerular filtration rate in normal

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subjects (10, 13, 28) and in patients suffering from renal disease (1, 24). Low protein diets have been reported to retard or even halt the progression of renal failure to end-stage renal disease (22, 25).

It has been demonstrated that elite male athletes have daily protein intake over  $1.5\text{g} \cdot \text{kg}^{-1}$  (4, 6, 15, 26). It has been said there is no reason to suspect that intake at that level (up to  $2.0\text{g} \cdot \text{kg}^{-1}$ ) by athletes will be detrimental to kidney function (18, 19). However, this assertion has not been adequately substantiated. Data need to be collected concerning any side effects on the kidney caused by high protein intake as usually observed with body-builders. Appropriate assessment of renal function at rest could include measures of renal hyperfiltration and glomerular permeability, as well as measures of protein and calcium balance in two groups of athletes having different protein intake.

To address this issue, we estimated glomerular filtration rate (creatinine clearance), potential change in glomerular membrane permeability (albumin excretion rate), nitrogen and calcium balances, and modification in the concentration-dilution properties of the kidney (free water clearance). In addition to the resting condition, we wanted to determine whether a high protein intake could worsen the transient impairment on kidney function induced by brief, heavy exercise commonly observed under these circumstances (23). Thus the purpose of this investigation was to determine whether high protein intake commonly observed in some trained athletes is detrimental to kidney function.

## Methodology and Techniques

Two groups of young male competitive athletes, matched for age and weekly training hours, served as subjects: Group BB consisted of 20 body-builders; Group OA consisted of other athletes, namely 13 cyclists, 2 judoka, and 3 rowers. These athletes had trained from 10 to 15 hours a week for several years. They could not be matched for weight and  $\text{VO}_2\text{max}$ , due to their specific physical activities. Both groups asserted they were not on anabolic steroids or other drugs, but this assertion could not be verified. All subjects gave their full agreement to participate to this study, which was approved by the Ethics Committee of the Faculty of Medicine of the Free University of Brussels.

### *Diet Analyses*

Each subject completed a 7-day nutrition record representative of typical training days in order to estimate total energy, protein, and calcium intakes. The subjects were instructed to continue their usual eating habits for over a month prior to the investigation. A detailed food record, including all portion sizes, was designed to obtain qualitative and quantitative data on nutrient intakes. The subjects were also asked to record brand names of commercial foods consumed and method of preparation. They received instruction on common household measures (grams, ml), and a conversion table was provided to enable a better estimation of quantities of food and beverages consumed. The subjects returned the completed food records when arriving at the laboratory; each was reviewed for completeness of the information. The Nutritionist III software was used to assess dietary intake. When applicable, subjects included information on any additional protein supplements (usually in powder form).

The limitation of this food record is that it is restricted to the brief period of the study and does not take into account seasonal variation or training status. However, this investigation was intended to show the relationship between protein intake and its potential renal disturbances; it was not intended to be a definite answer on the daily allowance for athletes. That would require a more extended survey. A further limitation to this study is that the single 7-day food analysis does not indicate these athletes always consume this level of protein. Nevertheless, they claimed to remain on their specific nutritional status over a 1-month period.

### **Blood and Urine Analyses**

Resting blood samples taken between 8 and 9 a.m. after an overnight fast and 24-hr urine from the previous day were obtained on the 7th day of the study to measure biological parameters and to estimate kidney function.

Blood analyses: albumin (5) and lactate (7) were assayed by colorimetric and enzymatic techniques, respectively. The automatic Hitachi 747 (Japan) determined creatinine (Boehringer Mannheim, Creatinine PAP, No. 839434), urea (Sigma Diagnostic, Urea, No. 640A), and uric acid (Boehringer Mannheim, UA Plus, No. 1661914), calcium (Boehringer Mannheim, Calcium, No. 1553593). Osmolality was calculated from the Hitachi assays on sodium, glucose and urea.

Urine analyses: Creatinine, urea, uric acid, and calcium were measured by the same techniques as applied to blood. Albumin was determined via immunochemical assay (20). Total nitrogen excretion was analyzed by the micro Kjeldhal method (Büchi nitrogen determination System, Switzerland) on the 24-hr urine collection. Osmolality was calculated from the Hitachi measures on sodium and urea.

### **Exercise Testing**

Both groups of athletes underwent stepwise maximal exercise on a cycle ergometer to assess maximal aerobic power and to estimate, under these conditions, the modifications of some renal functions. The exercise test consisted of ergometer cycling using a stepwise increase of load (30W) every minute until exhaustion. Conventional oxygen and carbon dioxide equipment (Ergopneumotest Jaeger) was used to assess maximal work capacity.

### **Calculations**

Apparent nitrogen balance was estimated by measuring dietary nitrogen intake from the diet data collection and urinary nitrogen output. For practical reasons, fecal and integumental nitrogen losses were not taken into account. Generally, sweat and fecal losses amount to 3 and 12 mg · kg<sup>-1</sup> b · wt per day, respectively (12). These values of estimated integumental and fecal losses can be used to correct for the differences obtained via nitrogen intake and urinary nitrogen loss measured in the present investigation. As the analysis of daily protein intake over the week did not show any statistical difference, the mean value was used for calculating the apparent nitrogen balance. Individual renal clearances were calculated from plasma and urine determinations and urine output according to the general formula (urine concentration/plasma concentration) (units per ml) × urine output (ml per min). Glomerular filtration rates were estimated from creatinine values.

### Statistical Analyses

All data are presented as means  $\pm$  standard errors (*SE*). The Friedman nonparametric test was used to determine any variation of protein intake over the week of food recording. To evaluate significant differences between groups, we used a nonparametric method (Mann-Whitney test). Regression lines and correlation coefficients were computed for selected variables. Significance for statistical tests was established at  $p < 0.05$ .

### Results

Table 1 reports the physiological responses to cycle ergometer of both groups. Group BB was heavier while Group OA had a higher maximal oxygen consumption. Maximal plasma lactate did not differ between groups. Table 2 lists the biological characteristics of both groups. Group BB had higher plasma levels for plasma creatinine, uric acid, and calcium, and they excreted more albumin in their urine collected under resting conditions ( $p < 0.05$ ). There were no statistical differences for creatinine and albumin clearances between groups, but the urea clearance of Group BB was lower. Calcium and free-water clearances did not differ between groups. Nevertheless, even if these differences were statistically significant, they remain within the upper and lower ranges of normal.

**Table 1 Physiological Characteristics of the Athletes**

	Group BB (n=20)	Group OA (n=17)
Age (yrs)	29 $\pm$ 1	28 $\pm$ 3
Body weight (kg)	86.4 $\pm$ 1.7	70.5 $\pm$ 3.2*
VO <sub>2</sub> peak (L·min <sup>-1</sup> )	3.61 $\pm$ 0.16	4.40 $\pm$ 0.23*
Maximal heart rate (bpm)	182 $\pm$ 3	182 $\pm$ 3
Maximal plasma lactate (mmol·L <sup>-1</sup> )	12.0 $\pm$ 0.5	11.4 $\pm$ 0.2

\* $p < 0.05$  between body-builders (BB) and other athletes (OA).

The results of the maximal stepwise exercise test are reported in Table 2. Both groups had similar lactate values at the end of exercise. While plasma levels of urea, uric acid, and calcium did not show any statistical differences between exercise and rest, there was a slight increase in creatinine in both groups (5–13%) due to the decrease in glomerular filtration rate (creatinine clearance). Indeed, all but one renal clearance was reduced (3–4%) under the exhaustive exercise test. The free-water clearance was even more reduced after exercise, demonstrating an enhanced concentration process in the renal tubules. By contrast, the albumin excretion rate and clearance were increased in the postexercise samples by about 18-fold. However, both groups had similar responses to the exercise test.

Table 3 presents the athletes' nutritional status. Mean energy intake, protein intake, total nitrogen balance, and calcium intake were higher in Group BB. However, the urine calcium excretion rate was not different in both groups.

Table 2 Biological Characteristics of the Athletes at Rest and After Maximal Exercise

	Group BB (n=20)		Group OA (n=17)	
	rest	exercise	rest	exercise
Plasma creatinine (mg·100 ml <sup>-1</sup> )	1.33 ± 0.03	1.40 ± 0.05 <sup>†</sup>	1.16 ± 0.04*	1.32* ± 0.06 <sup>†</sup>
Plasma urea (mg·100 ml <sup>-1</sup> )	40 ± 2	42 ± 3	36 ± 2	39 ± 3
Plasma uric acid (mg·100 ml <sup>-1</sup> )	4.9 ± 0.3	5.1 ± 0.3	4.2 ± 0.2*	4.5 ± 0.3
Plasma calcium (mg·100 ml <sup>-1</sup> )	9.8 ± 0.1	10.2 ± 0.1	9.5 ± 0.1*	9.9 ± 0.2
Albumin excretion rate (µg·min <sup>-1</sup> )	13.1 ± 2.0	161 ± 61 <sup>†</sup>	8.7 ± 1.8*	169 ± 40 <sup>†</sup>
Creatinine clearance (ml·min <sup>-1</sup> )	148 ± 6	97 ± 11 <sup>†</sup>	143 ± 5	99 ± 6 <sup>†</sup>
Urea clearance (ml·min <sup>-1</sup> )	60.4 ± 6.2	35.8 ± 5.4 <sup>†</sup>	78.2 ± 4.2*	50.3 ± 6.2 <sup>†</sup>
Calcium clearance (ml·min <sup>-1</sup> )	1.84 ± 0.25	1.04 ± 0.30 <sup>†</sup>	2.43 ± 0.30*	1.70 ± 1.31 <sup>†</sup>
Free-water clearance (ml·min <sup>-1</sup> )	-0.23 ± 0.02	-0.90 ± 0.20 <sup>†</sup>	-2.06 ± 0.57	-3.75 ± 0.50 <sup>†</sup>
Albumin clearance (µg·min <sup>-1</sup> )	0.18 ± 0.13	3.15 ± 1.21 <sup>†</sup>	0.17 ± 0.03	3.08 ± 0.71 <sup>†</sup>

\**p* < 0.05 between BB (body-builders) and OA (other athletes) at rest.<sup>†</sup>*p* < 0.05 between rest and exercise in each group.

**Table 3** Nutritional Status of the Athletes

	Group BB (n=20)	Group OA (n=17)
Energy intake (kcal·day <sup>-1</sup> )	3,908 ± 269	2,607 ± 254*
Total protein intake		
(g·day <sup>-1</sup> )	169 ± 13	99 ± 8*
(g·kg <sup>-1</sup> )	1.94 ± 0.13	1.35 ± 0.12*
(g N·g protein <sup>-1</sup> )	27.0 ± 2.1	15.8 ± 1.3*
Total N excretion (g·day <sup>-1</sup> )	17.1 ± 1.5	10.1 ± 1.3*
Apparent N balance (g·day <sup>-1</sup> ) <sup>†</sup>	8.48 ± 2.11	7.37 ± 2.47
Calcium		
intake (mg·day <sup>-1</sup> )	1,898 ± 307	1,094 ± 165*
urine excretion (mg·day <sup>-1</sup> )	310 ± 29	274 ± 18

\* $p < 0.05$  between BB (body-builders) and OA (other athletes).

<sup>†</sup>Protein is assumed to be 16% N.

Figures 1 through 4 show the relationships between protein intake and nitrogen balance, creatinine clearance, albumin excretion rate, and calcium excretion rate. It can be observed that the nitrogen balance became positive when daily protein intake was over  $1.26 \text{ g} \cdot \text{kg}^{-1} \text{ b} \cdot \text{wt}$  (Figure 1). A relationship between protein intake and the accumulation of N in the body is substantiated by a regression correlation ( $r^2 = 0.672$ ,  $p < 0.05$ ). However, protein intake does not appear related to changes in creatinine clearance (Figure 2), urine albumin excretion rate (Figure 3), or calcium excretion rate (Figure 4), with the data being scattered over a wide range. Four of the subjects had an albumin excretion rate above the upper limit of normal ( $20 \mu \text{g} \cdot \text{min}^{-1}$ ) unrelated to protein intake.

## Discussion

Lemon (17, 18) has said there is no reason to suspect that protein intake of  $1.2\text{--}2.0 \text{ g} \cdot \text{kg}^{-1} \text{ b} \cdot \text{wt}$  per day will cause any problem in athletes. This statement was not supported by any evaluation. The present investigation assessed several impairments commonly related to excess protein intake and a reduction in kidney function under pathological conditions (1–3, 8–10, 13, 22, 24, 25, 28, 29).

When comparing the daily protein intake of the groups (BB =  $1.94 \text{ g} \cdot \text{kg}^{-1}$ ; OA =  $1.35 \text{ g} \cdot \text{kg}^{-1}$ ), there were no major fundamental plasma differences for several variables usually associated with protein metabolism and renal impairment. Despite higher values for plasma creatinine, uric acid, and calcium levels ( $p < 0.05$ ), there was no accumulation of urea. Moreover, the glomerular filtration rate assessed by creatinine clearance did not differ between groups. Thus there was no sign of even moderate glomerular hyperfiltration which seems to precede the excretion of excess plasma protein into urine (3). The albumin clearance supports this observation. As noted, the higher value observed for Group BB remains within the upper limit of normal.

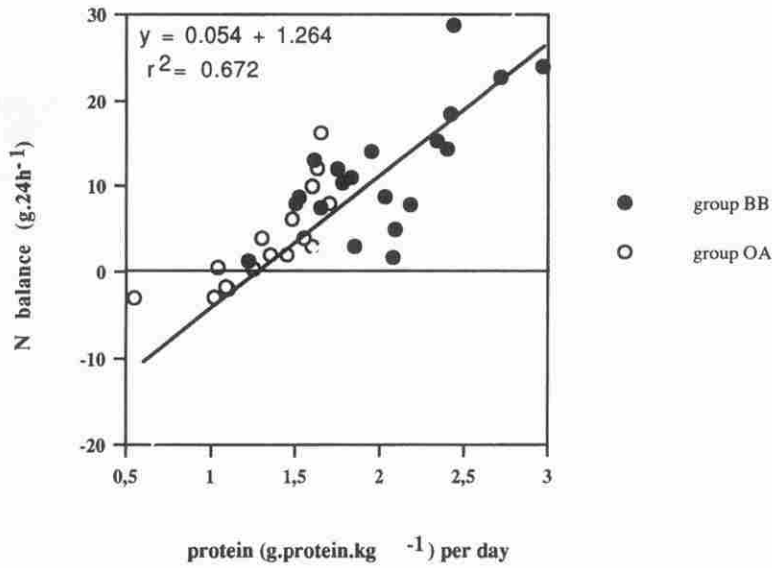


Figure 1 — Nitrogen balance (N) and daily protein intake in all athletes. There was a linear relationship between both variables ( $p < 0.05$ ) and a positive balance when protein intake exceeded  $1.26\text{g} \cdot \text{kg}^{-1}$ .

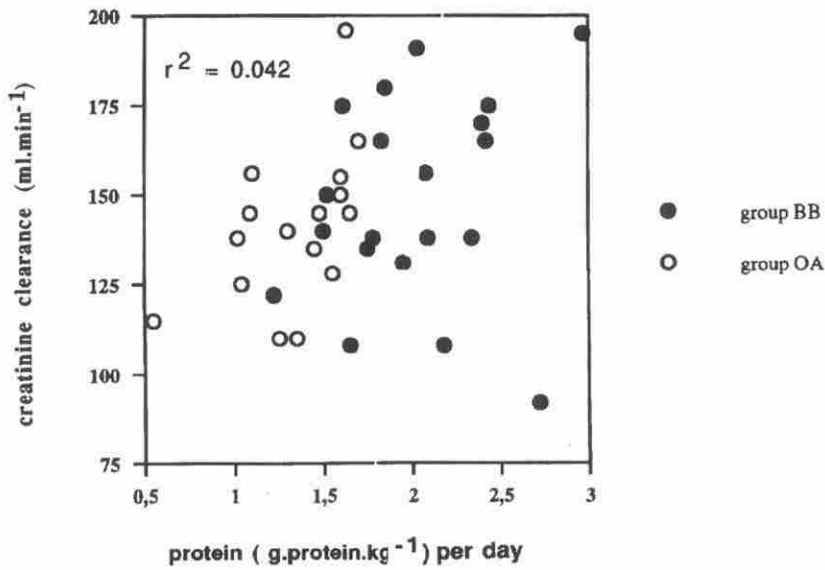


Figure 2 — Glomerular filtration rate, expressed as creatinine clearance and daily protein intake for both groups. There was no statistical relationship between both variables.

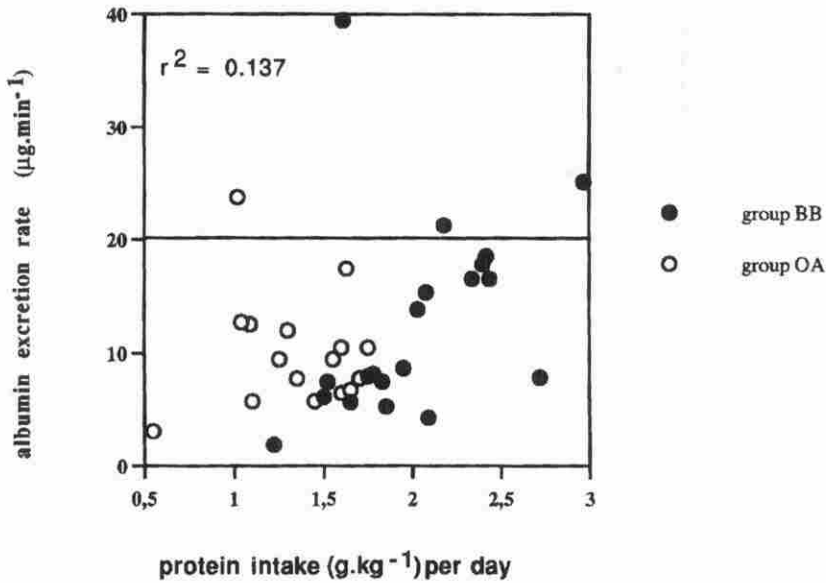


Figure 3 — Glomerular membrane permeability, expressed as albumin excretion rate, and daily protein intake for both groups. There was no statistical relationship between both variables. Most of the points are under the upper limit ( $20 \mu\text{g} \cdot \text{min}^{-1}$ ) of a healthy population under resting condition.

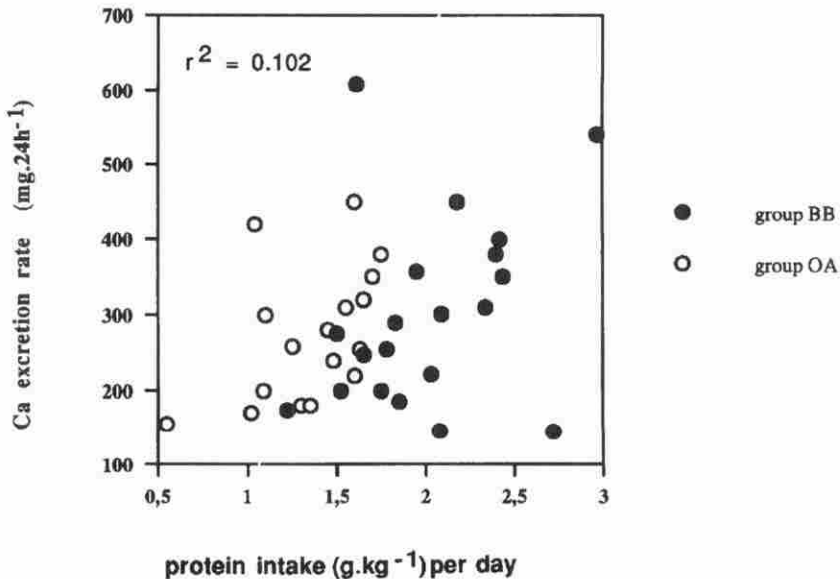


Figure 4 — Calcium excretion rate and daily protein intake for both groups. There was no statistical relationship between both variables.



The reduced value of urea clearance might be due to a lesser value of urine output by the body-builders ( $1.12 \pm 0.26$  ml/min) as compared to the other athletes ( $1.48 \pm 0.17$  ml/min). Indeed, urea excretion is closely related to urine output. Meanwhile, this observation does not correlate with the higher protein intake of the body-builders. The free-water clearances were nearly identical at rest for both groups. Its negative values indicate that the urine was hyperosmotic because the subjects were able to reabsorb solute-free water into the systemic circulation (16).

Nutritional status reveals that, as expected, Group BB had a higher daily protein intake near  $2.0 \text{ g} \cdot \text{kg}^{-1} \text{ b} \cdot \text{wt}$  vs.  $1.35 \text{ g} \cdot \text{kg}^{-1} \text{ b} \cdot \text{wt}$  for Group OA. Indeed, they had a higher nitrogen excretion but their average nitrogen balance was not statistically different from that of Group OA. Even though the body-builders had a higher calcium intake per day, there was no difference in calcium excretion rate vs. Group OA. It is generally accepted that changes in dietary protein alter urinary calcium excretion (21). The absence of modification at the urine site might be due to a higher excretion of calcium in the feces (14), which were not investigated in the present study. An alternative hypothesis may be that Group BB has a greater requirement, thanks to a greater load placed upon the musculoskeletal system due to training, leading to a higher retention of calcium.

Microalbuminuria is thought to reflect the glomerular component of a systematic capillary leak that is fundamental to the pathogenesis of multiple organ failure (11). Although the glomerular filtration and albumin excretion rates were higher in Group BB, there does not seem to be a direct correlation with daily protein intake. The results are widely scattered, and at up to  $2.8 \text{ g} \cdot \text{kg}^{-1} \text{ b} \cdot \text{wt}$  of protein intake, most subjects had an albumin excretion rate and clearance within normal ranges, respectively  $<20 \mu \text{g} \cdot \text{min}^{-1}$  and  $<0.20 \mu \text{L} \cdot \text{min}^{-1}$ . However 4 subjects had higher values for glomerular filtration and albumin excretion rates, perhaps due to strenuous exercise the previous day (23).

The exercise protocol (Table 2) revealed that both groups had similar responses to maximal load. The reduction of several clearances (creatinine, urea, uric acid, calcium) by 31 to 44% is in line with reported observations (23). The decrease in creatinine clearance in the postexercise samples demonstrated a reduction in glomerular filtration rate whereby the kidney acts to redistribute blood to the active muscles in order to maintain water homeostasis. Apparently, the higher protein intake of Group BB did not have any influence on the kidney responses to exercise as compared to Group OA.

## Conclusion

From the present study we conclude the following: (a) Despite several plasma and urine modifications induced by high protein intake ( $\sim 170$ – $243\%$  of the recommended dietary allowances) (12), there is no real impairment on kidney function as indicated by glomerular filtration rate and by albumin and calcium excretion rates. (b) The slight variations toward the upper range of normal distribution are not strictly related to the increase in protein above  $1.5 \text{ g} \cdot \text{kg}^{-1} \text{ b} \cdot \text{wt}$ , suggesting that individual differences play an important role in this regard. (c) Up to  $2.8 \text{ g} \cdot \text{kg}^{-1} \text{ b} \cdot \text{wt}$  of daily protein intake, we cannot detect any serious harmful effects from high dietary protein intake. Clinical measures of renal function do not appear to indicate renal stress in trained athletes who consume a high protein diet as measured in this study.

## References

1. Ando, A., T. Kawata, Y. Hara, M. Yaegashi, and N. Sigino. Effects of dietary protein intake on renal function in humans. *Kidney Int.* 36(Suppl. 27): S64-S67, 1989.
2. Benabe, J.E., and M. Martinez-Maldonado. Renal effects of dietary protein excess and deprivation. *Sem. Nephrol.* 11:76-85, 1991.
3. Brenner, M.B., T.W. Meyer, and T.H. Hostetter. Dietary protein intake and the progressive nature of kidney disease: the role of hemodynamically mediated glomerular injury in the pathogenesis of progressive sclerosis in aging, renal ablation and intrinsic renal disease. *N. Engl. J. Med.* 307:652-659, 1982.
4. Burke, L.M., R.A. Gollan, and R.S. Read. Dietary intakes and food use of elite Australian male athletes. *Int. J. Sports Nutr.* 1:378-394, 1991.
5. Doumas, B.T., W.A. Watson, and H.G. Briggs. Albumin standards and the measurement of serum albumin with bromocresol green. *Clin. Chim. Acta.* 31:87-96, 1971.
6. Eden, B.D., and P.J. Abernethy. Nutritional intake during an ultraendurance running race. *Int. J. Sports Nutr.* 4:166-174, 1994.
7. Gutmann, I., and A.W. Wahlefeld. L-(+)-Lactate. Determination with lactate dehydrogenase and NAD. In *Methods of Enzymatic Analysis*, H.U. Bergmeyer (Ed.). New York: Academic Press, 1974, pp. 1464-1468.
8. Heaney, R.P. Protein intake and the calcium economy. *J. Am. Diet. Assoc.* 93:1259-1260, 1993.
9. Hegsted, M., S.A. Schultle, M.B. Zemel, and H.M. Linkswiler. Urinary calcium and calcium balance in young men affected by level of protein and inorganic phosphate intake. *J. Nutr.* 111:553-562, 1981.
10. Hostetter, T.H. Human renal response to a meat meal. *Am. J. Physiol.* 250: F613-F618, 1986.
11. Jensen, J., K. Borch-Johnson, G. Jensen, and B. Feldt-Rasmussen. Microalbuminuria reflects a generalized transvascular albumin leakiness in clinically healthy subjects. *Clin. Sci.* 88:629-633, 1995.
12. Joint Expert Committee, FAO/WHO. *Energy and Protein Requirements*. Geneva: WHO, 1986. Tech. Rep. Series No. 724. (226 pp.)
13. Jones, M.G., K. Lee, and R.W. Swaminathan. The effect of dietary protein on glomerular filtration rate in normal subjects. *Clin. Nephrol.* 27:71-75, 1987.
14. Kerstetter, J.E., K.O. O'Brien, and K.L. Insogna. Dietary protein affects intestinal calcium absorption. *Am. J. Clin. Nutr.* 68:859-865, 1998.
15. Kleiner, S.M., T.L. Bazzarre, and B.E. Ainsworth. Nutritional status of nationally ranked elite bodybuilders. *Int. J. Sports Nutr.* 4:54-69, 1994.
16. Koeppen, B.M., and B.A. Stanton. *Renal Physiology*. St Louis: Mosby-Year Book, 1992.
17. Lemon, P.W. Is increased dietary protein necessary or beneficial for individuals with a physically active lifestyle? *Nutr. Rev.* 54:169-175, 1996.
18. Lemon, P.W.R. Effect of exercise on protein requirements. *J. Sports Sci.* 9:53-70, 1991.
19. McCarthy, P. How much protein do athletes really need? *Phys. Sportsmed.* 17:170-175, 1989.
20. Metzmann, E. Protein quantitation of both branches of the Heidelberger curve by monitoring the kinetic of immunoprecipitation. *Behring Inst. Mitt.* 78:167-175, 1985.
21. Pannemans, D.L.E., G. Schaafsma, and K.R. Westerterp. Calcium excretion, apparent calcium absorption and calcium balance in young and elderly subjects: influence of protein intake. *Br. J. Nutr.* 77:721-729, 1997.

22. Pedersen, M.M., C.E. Mogensen, F.S. Jorgensen, B. Moller, G. Lykke, and O. Pedersen. Renal effects from limitation of high dietary protein in normoalbuminuric diabetic patients. *Kidney Int.* 36(Suppl. 27): 115-121, 1989.
23. Poortmans, J.R., and J. Vanderstraeten. Kidney function during exercise in healthy and diseased humans. *Sports Med.* 18:419-437, 1994.
24. Rosenberg, M.E. J.E. Swanson, B.L. Thomas, and T.H. Hostetter. Glomerular and hormonal responses to dietary protein intake in human renal disease. *Am. J. Physiol.* 253: F1083-F1090, 1987.
25. Salahudeen, A.K., T.H. Hostetter, S.K. Raatz, and M.E. Rosenberg. Effects of dietary protein in patients with chronic renal transplant rejection. *Kidney Int.* 41:183-190, 1992.
26. Saris, W.H.M., M.A. van Erp-Baart, F. Brouns, K.R. Westerterp, and F. ten Hoor. Study on food intake and energy expenditure during the extreme sustained exercise. The Tour de France. *Int. J. Sports Med.* 10:S26-S31, 1989.
27. Slavin, J.L., G. Lanners, and M.A. Engstrom. Amino acid supplements: beneficial or risky? *Phys. Sportsmed.* 16:221-224, 1988.
28. Sølling, K., C.K. Christensen, J. Sølling, J. Sandahl Christiansen, and C.E. Mogensen. Effect on renal hemodynamics, glomerular filtration rate and albumin excretion of high oral protein load. *Scand. J. Clin. Lab. Invest.* 46:351-357, 1986.
29. Spencer, H., L. Kramer, D. Osis, and C. Norris. Effect of a high protein (meat) intake on calcium metabolism in man. *Am. J. Clin. Nutr.* 31:2167-2180, 1978.

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