Original article

Can Elastography Visualize Kidney Changes In Bodybuilders With High Protein Intake?

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Summary. *Introduction:* High protein nutrition is postulated to change kidney function and morphology in bodybuilding athletes. The ultrasound elastography technique is an examination method in which tissue stiffness is evaluated in numerical expressions. In our study, we investigated the correlation between kidney stiffness, kidney measurements and renal function tests of bodybuilding athletes who were fed with high protein diets. *Materials and Methods:* Bodybuilders (n=19) who were on a high-protein diet were compared with control subjects (n=20). Blood urea nitrogen/creatinine ratios and estimated glomerular filtration rates (eGFR) were calculated. Bodybuilders were divided into two subgroups according to eGFR levels (Group A and B for eGFR below or above 90; respectively). Length, width, volume, cortical thickness, and echogenicity of both kidneys were analyzed by ultrasound. Elastographic Shear Wave Velocity (SWV) measurements were performed, and the mean SWV values (m/s) were calculated for each kidney. Comparison of mean SWV values was performed between the groups and subgroups. *Results:* Mean BUN and serum Cr levels were higher in bodybuilders than control subjects ($p<0,05$). Cortical thicknesses and echogenicity were both higher in bodybuilders ($p<0,05$). The SWV values were higher in bodybuilders than the control group, indicating increased stiffness ($p<0,05$). Among bodybuilders, SWV values were significantly higher in group A than in group B ($p<0,001$). *Conclusions:* Elastography can be utilized for detection and follow-up of alterations in kidneys of bodybuilders or patients consuming high protein diets. High SWV can be considered as an indicator of renal damage, while the levels of conventional biomarkers may give confusing results.

Key words: elastography, kidney, protein, renal, stiffness

Introduction

Recently, high-protein diets are popular among athletes and people who want to reduce body fat tissue. Daily protein consumption is recommended as 0.8gr / kg for healthy people. For athletes, many studies that recommend protein intake to be in the range of 1.2-2.0 g / kg/day for muscle development and training adaptation (1). Additionally, bodybuilding athletes tend to use much more protein than these recommended values (2). Therefore, these athletes are at risk in terms of the systemic side effects of high protein diet.

Kidneys are one of the first organs to be affected by high protein nutrition. Increased blood flow increased glomerular pressure, blood and urine electrolyte changes are the main effects, and there are many studies in the literature stating that parenchymal damage may develop in the long term in bodybuilders (3).

Blood urea nitrogen (BUN), creatinine (Cr), BUN/Cr, estimated glomerular filtration rate (eGFR) values and ultrasound examinations are often sufficient as a basic screening procedure (4). However, these examinations do not always allow a specific assessment. BUN and Cr values can be detected high in non-renal reasons such as high protein diet, increased muscle mass, dehydration, use of creatinine supplements. In this case, ultrasound findings come to the fore in differential diagnosis. Kidney size and parenchymal echogenicity defined in grades are the main parameters evaluated in parenchymal pathologies, which may affect function.

Palpation is an indispensable part of physical examination and has been used for years in the evaluation of a lesion determined according to tissue hardness subjectively. The developing technology makes to make this evaluation more objective with elastography examination. Elastography provides tissue stiffness as numerical data independent of the practitioner and to present histological predictions according to the determined value. Elastography is mostly used in clinical practice to evaluate parenchyma and mass lesions in solid organs such as thyroid, breast, and liver (5).

Thus, in our study, we examined the kidneys of bodybuilding athletes with high protein nutrition, who are in the risk group for kidney damage, using an ultrasound elastography technique.

Methods

Nineteen male bodybuilders (mean age 31.6±10, BMI 26.8±2.4) and twenty healthy individuals were included in the study. Bodybuilders were under routine follow-up once or twice a year. Subjects in the control group had normal kidney function and ultrasound results. The bodybuilders underwent resistance training for an average of 6.5±3.5 hours per week for longer than two years. Their diet lists were all monitored and recorded by a trainer. None of the participants' exercise programs or diet lists were prepared intentionally for the study.

All bodybuilders were on a high-protein diet, which included natural food and various commercial protein powders voluntarily. Diet lists were prepared weekly to include different amounts of protein on the training days and rest days. All bodybuilders were following these diet lists consistently during the previous three months.

The amounts of protein provided by natural foods (i.e., dietary protein intake) such as eggs, white or red meat, cheese, vegetables were calculated using the program Nutribase®. The calculation of the amount of protein provided by protein-containing supplements such as commercial protein powders (protein intake supplementation) was accomplished by considering the brand, protein content in one serving and number of servings taken per day. The daily average value was calculated by dividing the total weekly protein intake by seven. None of the bodybuilders was using anabolic steroids or drugs which might affect renal function and consumed alcohol recently. Patients with known kidney disease, history of kidney surgery or kidney stone were excluded from the study.

The control group subjects followed a unique diet program prepared by a dietician with balanced nutritional contents to contain reasonable amounts of protein (<0.8gr/kg/day) and these subjects exercised regularly once or twice a week. Normal renal function test results and sonographic features were an inclusion criterion for the control group.

Venous blood samples were collected after the patients had fasted overnight. Samples were drawn from an antecubital vein, immediately transferred to glass tubes and centrifuged at 4500 rpm for 15 minutes. Serum concentrations of BUN and Cr were measured by photometric methods adapted to an autoanalyzer (Roche Hitachi Cobas 6000 Tokyo, Japan), and the BUN/Cr ratio was evaluated.

eGFR was calculated using the Modification of Diet in Renal Disease (MDRD) formula: eGFR= 186 x serum Cr-1.154 x age-0.203. According to eGFR, bodybuilders were classified as group A that consisted of subjects with eGFR below 90 and group B with eGFR above 90. Spot urine microalbumin, calcium, sodium, chlorine and potassium levels were measured by an autoanalyzer (Cobas 6000 with microalbumin kit, calcium kit and ion-selective methods).

Ultrasound measurements were performed using a real-time ultrasound machine (Philips Affiniti 70) with a curvilinear transducer of 5-1 MHz bandwidth frequencies. Abdominal preset settings in the machine software were selected before taking the measurements. Data were collected separately from both kidneys. The same radiologist obtained renal measurements while the subjects were in the right and left lateral decubitus position. Renal lengths were measured as the longest distance between the superior and inferior poles of the kidneys in the longitudinal axis. Width and thickness of kidneys were measured in a transverse section perpendicular to the longitudinal axis as the longest distance between the medial-lateral and ventral-dorsal borders of the kidneys. Cortical thickness was measured as the distance between the renal capsule and sinus in the transverse plane.

Renal volume was calculated automatically by the machine's software. Cortical echogenicity was graded in four groups: less cortical echogenicity than the liver: grade 0; equal cortical echogenicity to the liver: grade 1; higher cortical echogenicity than liver: grade 2 and loss of cortex-medulla differentiation: grade 3.

Shear wave velocity (SWV), which is generated by the acoustic radiation force impulse (ARFI) method, was measured by Philips Affinity 70 ultrasound system using a 5-1 MHz convex probe. The SWV measurements were performed in the right and left lateral decubitus position at multiple breath-hold times according to patient capacity. The maximum penetration depth was 8 cm and region of interest (ROI) cursor size was set to 0.5x1.5 cm. The ROI cursor was set to cortex and care was taken not to include the medulla. Measurements were taken at lower, mid and upper poles of each kidney. To prevent respiratory motion, SWV was measured at five consecutive breath-hold times at each pole for each kidney. Mean SWV value for each kidney was calculated based on these 15 SWV values and expressed in meters per second (m/s). A comparison of the mean SWV values was performed.

All statistical analyses were performed using SPSS (Statistical Package for Social Sciences for Windows, Version 16.0. Chicago, US) software. Pearson's product-moment correlation coefficient was used for analyses. Data were given as means ± standard deviations, percentages, frequency distributions and p value less than o.o5 ($p \leq 0.05$) was considered statistically significant.

This study was carried out following the Declaration of Helsinki. The study protocol was approved by the Ethics Committee of Dokuz Eylul University, Faculty of Medicine.

Results

In this study, 19 male bodybuilders (mean age 31.6±10, BMI 26.8±2.4) and 20 healthy individuals were included. Data including age, weight, height and BMI of all participants are presented in Table1. There were no differences between groups in terms of these parameters ($p>0.05$). Daily protein intake was significantly higher in the bodybuilders than the sedentary group ($p< 0.001$).

Mean serum BUN ($p=0.004$) and Cr ($p=0.001$) levels were significantly higher in bodybuilders than the control group (Table 1). The eGFR range was 66.5 - 142.5 mL/min (mean 99.22±23) in bodybuilders. Among all bodybuilders, 9 had an eGFR of less than 90 (mean 79±8). Microalbumin, calcium, sodium, chlorine and potassium levels were normal in spot urine samples.

Cortical thicknesses and echogenicity of both right and left kidneys were significantly higher in the bodybuilders than in sedentary participants. Kidney echogenicity was grade 1 in 11 (57.8%) of

Table 1. Physical characteristics, blood biochemistry and renal parameters of the subjects

	Groups (Mean±SD)		
Parameters	**Bodybuilder (n=19)**	**Control (n=20)**	*p value*
Age	31.6± 10	31.1± 7	
Height (cm)	1.79±.06	1.74±.08	*0.68*
Weight (kg)	85.6±4.4	81.6±8.9	*0.85*
BMI (kg/m^2)	26.80±2.4	26.84±2.7	*0.96*
Daily protein amount (gr/kg/day)	2.22±0.45	0.8±0.34	*0.001**

Table 1 (*Continued*)

Table 1. Physical characteristics, blood biochemistry and renal parameters of the subjects (*Continued*)

	Groups (Mean±SD)		
Parameters	**Bodybuilder (n=19)**	**Control (n=20)**	*p value*
BUN (mg/dl)	40.9 ± 7.7	35.7 ± 8.7	*0.004**
Cr (mg/dl)	0.98 ± .18	0.74 ± .11	*0.001**
eGFR (ml/min/1.73m^2)	99.22 ± 23	134 ± 27	*0.001**
Right total volume (cm^3)	151 ± 50	154 ± 44	*0.38*
Left total volume (cm^3)	159± 54	157 ± 7	*0.25*
Right cortical thickness (mm)	14.2 ± 2.7	10.6 ±1.2	*0.001**
Left cortical thickness (mm)	13.9 ± 2.1	10.7 ± 1.2	*0.002**
SWV1	1.9 ± .49	1.05 ±.23	*0.001**
SWV2	2.05±.53	0.90 ±.22	*0.001**
SWV3	1.96 ±.50	0.99 ± .25	*0.001**
SWV4	1.96±.48	0.97±.25	*0.001**
SWV5	1.99±.52	0.92±.24	*0.001**

Values are expressed as mean±SD. BMI: body mass index; BUN: blood urea nitrogen; Cr: Creatinine; eGFR: estimated glomerular filtration rate; SWV: Shear wave velocity; SD: Standard deviation; *p<0, 05: Statistically significant difference

Table 2. Renal parameters of bodybuilders as per eGFR level

	Groups (Mean±SD)		
Parameters	**Group A (n=9)**	**Group B (n=10)**	***p values***
eGFR (ml/min/173m^2)	79±8	117±17	*0.001**
Right total volume (cm^3)	156 ± 63	146±38	*0.70*
Left total volume (cm^3)	155 ±51	164±58	*0.73*
Right parenchyma thickness (mm)	14.3±2.8	14.1±2.7	*0.91*
Left parenchyma thickness (mm)	13.9 ± 2.3	13.9±2.1	*0.98*
SWV1	1.9 ±0.2	1.9±0.36	*0.80*
SWV2	2.1 ±0.34	1.9±0.21	*0. 17*
SWV3	1.9 ± 0.32	1.9±0.36	*0.74*
SWV4	2.0±.25	1.8±0.4	*0.28*
SWV5	2.0±.32	1.9±0.34	*0.55*

Values are expressed as mean±SD. eGFR: estimated glomerular filtration rate; SWV: Shear wave velocity; *p<0, 05: Statistically significant difference

bodybuilders and grade 2 in 2 (10.5%) bodybuilders. However, there were no differences between the groups in terms of renal volumes (p=0.38 and p=0.25 for right and left kidneys, respectively) (Table 1). The SWV values were also significantly higher in the bodybuilders than in the control group, indicating increased stiffness (p<0.001) (Table 1). Among bodybuilders, SWV values were significantly higher in group A than in group B (p<0.001) (Table 2).

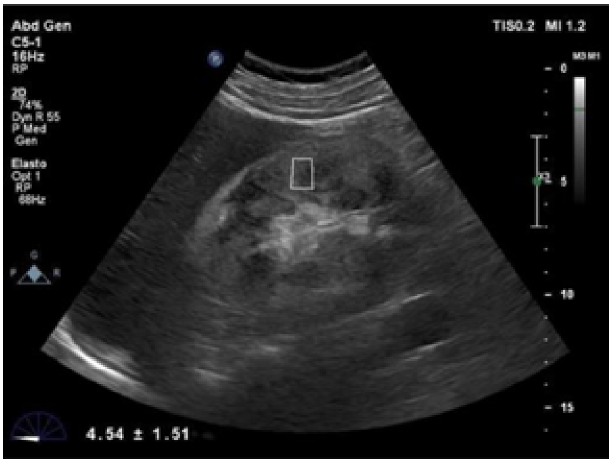

Figure 1. Placement of the 'region of interest' cursor onto the renal parenchymal image of a bodybuilder with increased kidney echogenicity and cortical thickness

Discussion

Results of this study suggest that regularly consuming a high-protein diet may cause high SWV, indicating increased renal stiffness and morphological alterations. The main findings of the current study supporting this conclusion are: (i) High SWV in bodybuilders compared with normal individuals (ii) High SWV with relatively low eGFR among bodybuilders and (iii) High cortical thickness and echogenicity in bodybuilders compared to normal individuals.

High protein diet is recommended for healthy individuals, athletes and individuals with chronic diseases such as diabetes, obesity, and chronic kidney failure. Although there is no clear definition of high protein nutrition in the literature, use in the range of 1.2-2 g / g / day or> 1.5 g / kg / day is accepted as a high protein diet[3]. Additionally, 2.4-4.5gr / kg / day protein intake has been reported among bodybuilding athletes and these values are far above the recommended (6). Although a certain proportion of these proteins can be obtained from natural foods, it is known that the use of synthetic products such as commercial protein powders, amino-acid complexes and substances such as creatinine to reduce calories has increased recently.

Kidney health is crucial for athletes who consume high protein diets. In animal and human studies, high protein diets are postulated to have functional and morphological effects on kidneys that accelerate chronic kidney disease. Studies that demonstrated the damaging effects of high protein intake on kidneys explained these findings by high blood flow causing increased glomerular pressure and induction of vasodilatation due to protein-induced hyperemia (7,8). High urinary calcium excretion, which increases the risk of stone formation, was also detected in healthy subjects following a high protein diet for six weeks (8).

High protein diets may cause increased serum urea, uric acid, creatinine, eGFR and urinary calcium excretion. Thus, these biomarkers have some limitations to detect kidney health (4). Catabolic stages related to training type and hydration status can have a significant effect on serum urea levels. High muscle mass, together with creatinine supplementation -which is widely used among bodybuilders- may cause a rise in both serum and urine creatinine levels (1). As in our study , high serum creatinine levels may cause falsely low eGFR results and conceal a high eGFR value in subjects with high protein intake. For this purpose, ultrasound imagining and some other biomarkers such as cystatin C, beta 2-microglobulin and retinol-binding protein which are not affected by age, muscle mass or diet have been used to show the renal function more specifically (9).

Conventional renal ultrasound provides information such as kidney volume, corticomedullary differentiation, cortical thickness and echogenicity, which gives findings on parenchymal disease (10). Considering that ultrasound examinations are subjective due to operator dependency, new technologies such as elastography examination have been used more in the diagnosis of some diseases in recent years (11). The stiffness of an organ depends on the blood flow and the interstitial structure of the organ. There are studies in the literature indicating that renal blood flow is the main factor in determining kidney stiffness since receiving 20% of cardiac output. Additionally, interstitial fibrotic tissue is another important factor in stiffness of kidney (12,13). It was also reported that the quantification of tissue stiffness in kidneys by ultrasound is more complicated compared to liver and thyroid due to the high tissue heterogeneities and rapidly blood flow alterations (13). Studies regarding elastography of kidneys have been conducted mostly in adults or pediatric patients with end-stage renal disease, transplanted kidneys, renal tumors and hydronephrosis (14,15). Most of these studies depended on the evaluation of irreversible interstitial fibrosis, tubular atrophy and glomerular sclerosis that eventually lead to graft loss in renal transplant patients or on detection of fibrosis level in the setting of end-stage renal disease (16). A series of small solid renal tumors were evaluated by elastography have also been reported (17). Our study is the first study to evaluate kidneys by elastography in bodybuilding athletes, and the high values we found suggest that elastography is useful to evaluate the effects of high protein diets on kidneys. We believe that these findings may be related to increased glomerular filtration, vasodilatation and glomerular injury due to the consumption of a high-protein diet. According to our study results, we think that the finding of the coexistence of enlargement of kidney dimensions with increased echogenicity suggests a parenchymal affection. This involvement may be due to increased blood flow or may suggest the presence of an infiltrative and/or inflammatory process. Although the kidney-based cause-effect relationships can only be established by histopathological confirmation after standard diets with a standard exercise program in the long term in athletes it is challenging to create these conditions in real life. Therefore, non-invasive investigations such conventional ultrasound with elastography examination may come fore to assess kidney health. Considering that histopathological examinations are invasive and laboratory tests have some limitations during high protein consumption radiologic imagining findings may provide more information with the developing technology. Additionally, reversibility is an essential factor in the follow-up after exposure to a substance that may have side effects, conventional ultrasound with elastography evaluation seems to be an ideal investigation for monitoring athletes consuming high protein diet in terms of renal health. Low price, reproducibility and easy accessibility are the additional advantages of this modality.

Our study has some limitations. First, we did not keep the subjects in a camp life where diet lists, hydration status and exercise programs were standardized. Besides, the new renal function biomarkers mentioned above were not analyzed in the context of this study.

In conclusion, owing to its low price, reproducibility, and easy accessibility, elastography evaluation might be an ideal imaging modality for detection and follow-up of the alterations in kidneys of bodybuilders consuming high protein diets. High SWV can be considered a reliable indicator of kidney damage, while the assessment of the levels of traditional biomarkers can give confusing results.

References

1. Schoenfeld BJ, Aragon AA. How much protein can the body use in a single meal for muscle-building? Implications for daily protein distribution. Vol. 15, Journal of the International Society of Sports Nutrition. 2018.
2. Ribeiro AS, Nunes JP, Schoenfeld BJ. Should Competitive Bodybuilders Ingest More Protein than Current Evidence-Based Recommendations? Sports Medicine. 2019; 49(10).
3. Ko GJ, Rhee CM, Kalantar-Zadeh K, Joshi S. The effects of high-protein diets on kidney health and longevity. Vol. 31, Journal of the American Society of Nephrology. 2020.
4. Takemoto Y, Naganuma T. Kidney function tests. Japanese Journal of Clinical Urology. 2012;66(4).
5. White J, Gay J, Farnsworth R, Mickas M, Kim K, Mattoon J. Ultrasound elastography of the liver, spleen, and kidneys in clinically normal cats. Veterinary Radiology and Ultrasound. 2014;55(4).
6. Spendlove J, Mitchell L, Gifford J, Hackett D, Slater G, Cobley S, et al. Dietary Intake of Competitive Bodybuilders. Vol. 45, Sports Medicine. 2015.
7. Friedman AN. High-protein diets: Potential effects on the kidney in renal health and disease. Vol. 44, American Journal of Kidney Diseases. 2004.
8. Gottlieb S. High protein diet brings risk of kidney stones. BMJ. 2002;325(7361).
9. Gowda S, Desai PB, Kulkarni SS, Hull V v, Math AAK, Vernekar SN. Markers of renal function tests. North American journal of medical sciences. 2010;2(4).
10. Szopiński T, Keller E, Zβťura F. Kidney Ultrasound - what is important for a urologist? Journal of Ultrasonography. 2016;16(67).
11. Duymuş M, Menzilcioğlu MS, Gök M, Avcu S. Kidney Ultrasound Elastography: Review. Kafkas Journal of Medical Sciences. 2016;6(2).
12. Peride I, Rădulescu D, Niculae A, Ene V, Bratu OG, Checheriță IA. Value of ultrasound elastography in the diagnosis of native kidney fibrosis. Vol. 18, Medical Ultrasonography. 2016.
13. Gao J, Thai A, Lee J, Fowlkes JB. Ultrasound Shear Wave Elastography and Doppler Sonography to Assess the Effect of Hydration on Human Kidneys: A Preliminary Observation. Ultrasound in Medicine and Biology. 2020;46(5).
14. Sigrist RMS, Liau J, Kaffas A el, Chammas MC, Willmann JK. Ultrasound elastography: Review of techniques and clinical applications. Vol. 7, Theranostics. 2017.
15. Qi R, Yang C, Zhu T. Advances of Contrast-Enhanced Ultrasonography and Elastography in Kidney Transplantation:

From Microscopic to Microcosmic. Vol. 47, Ultrasound in Medicine and Biology. 2021.
16. Gameraddin M. Ultrasound of the Kidneys: Application of Doppler and Elastography. In: Essentials of Abdominal Ultrasound. 2019.
17. Schneider CM. Ultrasound elastography for intra-operative use and renal tissue imaging. UBC Theses and Dissertations. 2017;(April).

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