Exercise: An Active Route to Healthy Aging

Glomerular Filtration Rate and Albumin Excretion After Maximal Exercise in Aging Sedentary and Active Men

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Background. From 30 years onwards there is a linear reduction of renal function of about 0.41% per year. Aging induces progressive impairment of glomeruli leading to an increase in protein excretion. The purpose of the present study was to investigate the effect of maximal exercise on glomerular filtration rate (GFR) and albumin excretion in an aging population.

Methods. This is a cross-sectional study from 213 healthy men, sedentary or endurance-trained, aged 20–30 and 50–80 years submitted to maximal exercise on a cycle ergometer. Blood and urine samples were obtained at rest and after the strenuous exercise. We evaluated the GFR by measuring creatinine clearance and the urine albumin excretion rate.

Results. After exercise, the older adults had a lesser reduction in GFR (mean 12%) than the young participants (mean 28%). As compared to those at rest, the increase of postexercise albumin excretion rates was lower in older participants (mean 7-fold) versus the young population (mean 20-fold). It appears that the exercise impact on some renal functions is related to the absolute load imposed on the individuals ($r^2 = 0.693$).

Conclusion. As far as GFR and urine albumin excretion are concerned, regular endurance training does not induce any signs of potential incipient nephropathy in a healthy aging population.

STRENUOUS exercise induces acute renal changes in healthy children (1) and adults (2). In young adults, exercise depresses renal plasma flow and glomerular filtration rates [GFRs (3–5)], and induces excretion of plasma proteins in the urine (6). Postexercise proteinuria is more specifically related to the intensity than to the duration of the exercise (7). Moreover, the excretion of plasma proteins is due primarily to enhanced glomerular membrane permeability associated with a saturation of the reabsorption process (8). These effects, which are intensity-dependent, are transient, with return to basal state with a half-life of about 1 hour (9).

Normal aging impairs all body function as a result of a linear decline of organ reserve from 30 year onwards (10). On the basis of the review of literature on 54,274 healthy, nonsmoking human participants of both sexes, we determined that the linear estimate of renal function loss averages 0.41% per year. Regular physical exercise appears to slow biological aging (11,12). However, few studies have investigated the renal responses to acute or repetitive exercises in older individuals (13–15). Farquhar and Kenney (13) reported that treadmill exercise (about 57% maximal oxygen consumption [VO$_{2\text{max}}$]) for 1 hour in the heat caused dramatic decreases in GFR and renal blood flow in healthy old individuals (64 years).

The purpose of the present study was to determine whether aging magnifies the effects of acute, strenuous maximal exercise on creatinine clearance and albumin excretion in the urine of healthy individuals.

METHODS

Participants

Two hundred twelve healthy men gave their free consent to participate in this study that was approved by the Ethical Committee of the Faculty of Medicine (Université Libre de Bruxelles). The participants were chosen as volunteers from the university community, either as students or staff members. They were nonsmokers and had no history of any chronic disease and no evidence of kidney or liver dysfunction. None of the participants were taking any medications. The participants were separated as active (a) or sedentary (s) individuals and thereafter into 4 arbitrary decennial groups each according to their age: Group A [20–30 years, $n (a) = 13$, $n (s) = 12$], Group B [50–59 years, $n (a) = 80$, $n (s) = 9$], Group C [60–69 years, $n (a) = 65$, $n (s) = 12$], and Group D [70–80 years, $n (a) = 19$, $n (s) = 6$]. The participants were chosen among physically active or sedentary students (Group A) and older either sedentary adults or individuals (Groups B–D) involved in different...
types of regular aerobic training (e.g., running, cycling, swimming, brisk walking) over 2000 kcal/wk. The weekly exercise expenditure, expressed in kilocalories, was estimated according to a questionnaire filled out by each individual (16). Briefly, each participant reported the type of endurance training, its intensity, and duration over 1 week.

**Protocol**

Each participant was examined by a physician, and had a resting electrocardiogram before completing a stepwise-increased exercise on a cycle ergometer (up to its maximal load). The participants collected their urine for a 2-hour period before the exercise test, and a blood sample from the left brachiocephalic vein was taken in the sitting position before getting on the bike. All blood samples were collected into heparin-containing vacutainers (Becton Dickinson Vacutainer, Meylan, France) immediately put on ice. Immediately before starting the exercise, the participants were provided with water at 5 ml/kg body weight.

The exercise bout consisted of a stepwise increase of 30 W every minute until exhaustion. Heart rate and precordial leads ECG (Medisoft-Medcard, Ciney, Belgium) were monitored throughout the entire exercise protocol. Respiratory parameters were measured during the whole exercise period by using an automated online system (Jaeger Ergopneumotest; Weisbaden, Germany) for oxygen and carbon dioxide concentrations, and expiratory volume analysis. VO$_{2\text{max}}$ was measured when the participant was no longer able to sustain the speed of 60 rpm. Respiratory exchange ratio values for all participants at peak exercise exceeded 1.05.

By the end of the exercise, the participants were also provided the same amount of water given at the start, and a second venous blood sample was taken at 5 minutes postexercise while sitting. Thirty minutes after the end of exercise, the participants voided their bladder to provide the second urine sample (“exercise urine”).

**Analyses**

Blood samples were immediately centrifuged at 4°C (10 minutes at 15000 g), and plasma was collected for further analyses. Creatinine concentrations in plasma and in urine samples were also determined by an enzymatic colorimetric test (Boehringer Mannheim, Mannheim, Germany). Plasma and urine albumin concentrations were measured by a specific monoclonal immunologic precipitation (17) using the Turbiquant technique (Behringwerke, Marburg, Germany). Preexercise urine clearances (Cl, $x = ([Ux]/[P,x]) \times Vu$) were calculated for creatinine and albumin concentrations ([x]) from blood and urine samples and volume (Vu) collected before the start, and postexercise clearances were calculated from blood samples collected immediately after stopping the exercise and from urine collected at 30 minutes postexercise.

**Statistical Analysis**

All data are reported as means ± standard error. For each age group, statistical differences between sedentary and active individuals were determined by using a two-tailed independent t test (Statview IV; Cary, NC). A p value ≤.05 was considered to be significant between sedentary and active individuals in each age group.

**RESULTS**

The characteristics of the participants are included in Table 1. As expected, the older participants (Groups B–D) had a higher body mass index but there were no significant differences in body mass index between the endurance-trained and sedentary older individuals. The active participants had an exercise energy expenditure largely greater than the weekly standard of 2000 kcal [as proposed by the American College of Sports Medicine for active people (18)]. The weekly exercise energy expenditure of the young participants was higher than that of the older active participants (about twice, $p < .05$).

The exercise cardiorespiratory and biochemical data are presented in Table 2. The reduction of maximal heart rate was related to aging, with no significant difference between active and nonactive individuals. Maximal power output and VO$_{2\text{max}}$ at the end of exhaustive exercise were also reduced with aging, but the values obtained by the active groups were always higher than those of the sedentary individuals ($p < .01$). Exercise induced a slight increase in plasma creatinine levels (from 2% to 13%), as expected by hemoconcentration. Urine creatinine levels were also slightly increased (whereas urine outputs were reduced) by exercise. There was no statistical difference in plasma or urine creatinine levels between each active and sedentary group.

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**Table 1. Characteristics of the Participants**

<table>
<thead>
<tr>
<th>Values</th>
<th>Group A (a) (N = 13)</th>
<th>Group A (s) (N = 12)</th>
<th>Group B (a) (N = 80)</th>
<th>Group B (s) (N = 9)</th>
<th>Group C (a) (N = 65)</th>
<th>Group C (s) (N = 12)</th>
<th>Group D (a) (N = 19)</th>
<th>Group D (s) (N = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>28 ± 3</td>
<td>26 ± 2</td>
<td>54 ± 1</td>
<td>56 ± 1</td>
<td>64 ± 1</td>
<td>64 ± 1</td>
<td>74 ± 2</td>
<td>74 ± 1</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>70.5 ± 3.2</td>
<td>73.9 ± 1.5</td>
<td>77.2 ± 0.9</td>
<td>80.0 ± 4.6</td>
<td>77.3 ± 1.3</td>
<td>75.6 ± 2.3</td>
<td>74.3 ± 2.8</td>
<td>75.3 ± 4.2</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.77 ± 0.02</td>
<td>1.79 ± 0.02</td>
<td>1.76 ± 0.07</td>
<td>1.73 ± 0.14</td>
<td>1.74 ± 0.08</td>
<td>1.73 ± 0.02</td>
<td>1.72 ± 0.03</td>
<td>1.71 ± 0.03</td>
</tr>
<tr>
<td>BMI</td>
<td>22.5 ± 0.3</td>
<td>23.1 ± 0.5</td>
<td>24.9 ± 0.2</td>
<td>26.7 ± 1.4</td>
<td>25.5 ± 0.3</td>
<td>25.3 ± 1.1</td>
<td>25.0 ± 0.7</td>
<td>25.6 ± 0.7</td>
</tr>
<tr>
<td>EE, kcal/wk</td>
<td>7680 ± 1576</td>
<td>3454 ± 298*</td>
<td>3561 ± 331*</td>
<td>3156 ± 565*</td>
<td></td>
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</table>

**Notes:** Values shown are mean ± standard error.

- Group A: 20–30 years; Group B: 50–59 years; Group C: 60–69 years; Group D: 70–80 years.
- a = active; s = sedentary; EE = exercise energy expenditure; BMI = body mass index.
Under resting conditions, the GFRs, as expressed as the creatinine clearances, were within the normal range for each age group (Figure 1). There was a small but significant reduction (p < .05) in the GFR (9%–15%) induced by the exercise in each age group, with no differences between those of the active and sedentary individuals. Resting excretion of urinary albumin was below the upper limit of normal for a healthy population (<20 μg/min) in all age groups, both active and sedentary. Figure 2 shows the postexercise albumin excretion rate for all groups of participants. The younger participants (20- to 30-year-old) had a mean albumin excretion rate of about 20-fold above the resting level. The older individuals had lower postexercise excretion rates for all groups of the active and sedentary individuals. Figure 1 shows a higher reduction of the glomerular filtration rate (about 12%), without any statistical difference between sedentary and endurance-trained old adults. Our results also showed that the renal hemodynamic responses to acute exercise in older adults are similar to those in young adults (2). Our results also showed that, as compared to rest condition, maximal exercise did not induce statistical vation of Farquhar and Kenney (13) and Kenney and Zappe (14) that moderate exercise (50%–60% VO_2max) for 1 hour reduced GFR by about 30% in 64-year-old women. They also reported that renal blood flow decreased by about 47% during exercise under these conditions. Declines in renal function during exercise are intensity-dependent (3,5,23,24) and generally in the range of 30%–60%. Our results collected on senior participants up to 80 years old extend these previous investigations obtained in young adults. Therefore, it appears that the renal hemodynamic responses to acute exercise in older adults are similar to those in young adults (2). Our results also showed that, as compared to rest condition, maximal exercise did not induce statistical
difference in plasma and urine levels and urine output when comparing each active group to its sedentary counterpart. As well, the exercise training status showed the same relative decline of GFR in the whole age range of our population, even at maximal exercise.

Urine protein excretion has been long recognized as a marker of glomerular disease in elderly patients (20). The mechanism of proteinuria involves modifications of membrane permeability. The excess protein excretion after exercise may be the consequence of two mechanisms, namely an increased membrane permeability of the glomeruli and a saturation of the tubular reabsorption process of filtered protein. It is useful to assess indirectly changes in glomerular membrane permeability by measuring the urine excretion rate of plasma albumin. We have provided evidence of an enhanced glomerular permeability induced by short-term strenuous exercise in young adults (8). It also appeared that postexercise proteinuria was more related to the intensity of the exercise (power output) than to its relative intensity (% of VO₂max) (7). Using the albumin excretion rate as evidence of dysfunction at the glomerular barrier, Figure 2 indicates that maximal exercise load did induce an enhanced glomerular membrane permeability change in young individuals, as reported previously (1,2,6–9). The excretion of albumin was lower, however, in elderly individuals despite the fact that they attained their maximal work capacity. Indeed, as an example, the 100% VO₂max for the active A group (20–30 years) is obtained with a power output of 355 W, whereas VO₂max for the active C group (60–69 years) occurred at 167 W. The outcome would probably have been different if the young and older groups had been compared after performing the same submaximal exercise. The purpose of the present investigation, however, was to determine if short-term strenuous exercise to maximum has a detrimental impact on the GFR and albumin excretion. The importance of the intensity of exercise on postexercise albuminuria is shown in Figure 3 using the maximal workload by the end of exercise in each age group ($r^2 = 0.693, p < .001$).

To conclude, the aging kidney is characterized by a decrease in renal blood flow and glomerular filtration mainly due to progressive glomerulosclerosis. Nevertheless, even in the presence of these changes, the kidney maintains its functionality until advanced age (25). There is a tendency, however, towards greater renal vasoconstriction in elderly individuals as compared to young individuals, especially during physical exercise. Acute renal failure might occur due to dehydration, such as is sometimes observed during exercise. Our results clearly show that strenuous exercise does not have any acute detrimental effect on kidney function in well-hydrated older persons and that the observed changes induced by the exercise (reduction in GFR, increase of albumin excretion) are less pronounced as compared to a young population. Repeated small biological insults can result, however, in cumulative damage. Younger individuals are more able to adjust blood distribution than are older individuals. Apparently, our endurance-trained seniors did not have any signs of incipient nephropathy, such as a further reduction in basal GFR or higher excretion of urine albumin when compared to sedentary individuals of the same age. To our knowledge, this basic observation in older individuals has not been reported previously.

**Acknowledgments**

This work was supported in part by a special grant from the Research Council of the Free University of Brussels.

We express our appreciation to Francine Reding for her excellent technical skills.

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**Figure 2.** Urine albumin excretion rate (mean ± standard error). The resting values (open bars) are within the normal population (<20 μg/min) of a healthy population from young individuals to older adults. The postexercise data express an increased glomerular membrane permeability with a higher impact on the young participants (20-fold the resting values) as compared to the older population (from 3- to 7-fold the resting values). The increase of postexercise albuminuria is smaller in the 70- to 80-year-old adults, both active and sedentary.

**Figure 3.** Relationship between the intensity of exercise and the excretion of urine albumin. Mean values for each group are reported. There is a statistical relationship ($r^2 = 0.693, p < .001$) between the maximal workload and the enhanced albumin excretion.
REFERENCES

Received October 5, 2005
Accepted February 25, 2006
Decision Editor: Luigi Ferrucci, MD, PhD

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