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Age-associated Changes in Renal Function After Exhaustive Exercise in Healthy Males Ranging in Age From 8~80 Years Old

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Abstract

SUZUKI, M., ISHIYAMA, I. and SEINO, T., Age-associated Changes in Renal Function After Exhaustive Exercise in Healthy Males Ranging in Age From 8~80 Years Old. Adv. Exerc. Sports Physiol., Vol.12, No.3 pp.65-72, 2006. This study was conducted to examine the effects of age on changes in renal function after exhaustive exercise in 162 healthy males ranging in age from 8 to 80 yrs. Voluntary exhaustive exercise was performed using a treadmill. $\dot{V}O_2max$ and HRmax were measured. Blood and urine samples were taken before, immediately after, and at 30/60 min after exercise. These specimens were used for measurements of electrolyte, lactate (LA), creatinine (Cr) and albumin concentrations. Cr clearance (Ccr) was calculated as an indicator of the glomerular filtration rate. $\dot{V}O_2max$, HRmax, and maximal concentration of blood LA (bLAmax), measured immediately after exercise, lowered with age while peaks of these variables occurred at differing ages, respectively. Urinary albumin excretion (UAE) rose remarkably 30 min after exercise ($UAE_{rec30\ min}$) in every age group. The highest increase in $UAE_{rec30\ min}$ was at 16~19 yrs of age, and thereafter gradually decreased with age. A highly positive correlation ($r=0.819$, $p<0.001$) was indicated between UAE and urinary LA excretion (ULAE). A remarkable reduction in the concentration of Cl^- compared to that of Na^+ in urine 30 min after exercise may compensate for an increase in the urinary anion gap, which was the greater part of the increase in ULAE. It is thought that the excess amount of LA produced by exercise was filtered through the glomerulus, and preferentially excreted into urine in order to normalize the acid-base balance disturbed by exercise. The present results suggest that the organic acids produced by exercise might alter renal glomerular permeability and/or inhibit reabsorption of albumin at proximal tubules while the precise mechanisms for exercise-induced albuminuria are still unknown.

It may be concluded that age-associated changes in renal function after exhaustive exercise might become fewer as the result of a reduction of energy production with aging in skeletal muscles during exercise.

Keywords: aging, physical exercise, renal function, albuminuria, acid-base balance

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Introduction

Physical fitness, including muscle strength (10, 13), aerobic work capacity (6, 23), etc, declines with aging. Relative intensity to maximum capacity in individuals, % of maximum strength or $\%\dot{V}O_2max$ are, therefore, used in exercise prescription for muscular and endurance training. On the other hand, the kidney makes no direct contribution to the performance of exercise, and reductions in renal plasma flow (RPF) and the glomerular filtration rate (GFR) as well as the appearance of proteinuria and hematuria depending on an increase in exercise intensity have been observed (8, 21). Physical exercise, namely, has negative effects on the kidney in terms of the maintenance of renal function. However, the kidneys play an important role in the recovery of the internal environment, such as disturbances of pH, osmotic pressure, and electrolytes in blood caused by exercise. Age-related reductions of RPF, which underlies the maintenance of renal functions such as GFR, excretion, and reabsorption in the renal tubules, have been recogniged (5). However, the effects of age on changes in renal function after exercise have not been reported to our knowledge. If decreases in renal function during exercise become remarkable with aging, it will be required to lower the relative exercise intensity, e.g. $\%\dot{V}O_2max$, depending on the age based on considerations of renal function.

The present study, therefore, was conducted to examine the effects of age on changes in renal function after exhaustive exercise in healthy males.

Methods

A. Subjects

One hundred and sixty two healthy male volunteers who ranged in age from 8 to 80 years, were disease-free, and were taking no medication, participated in the present

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study. The volunteers were fully informed and familiarized with all procedures prior to the experiment. In the case of juvenile participants, informed consent was obtained from both their guardians and the relevant school authorities. The present study was conducted in accordance with the Declaration of Helsinki under careful supervision including a medical history interview prior to testing, with monitoring of electrocardiography and blood pressure (BP) during the exercise test.

B. Experimental protocol

The experiment was carried out in a fasting state, the morning following an overnight fast. Thirty minutes later, they voided urine to empty the bladder. After an additional resting time of 30 min, BP was measured using a Riva-Rocci sphygmomanometer and a 10-ml blood sample was withdrawn from the brachial vein. Immediately after collection of the urine sample, body weight was measured. BP measurement and samplings for blood and urine were performed before, immediately after, and at 30/60 min after the exercise test while blood sampling was excluded at 60 min after. A maximal voluntary exercise test was performed using a treadmill. Taking age and whether daily regular exercise was done or not into consideration, running speed (4~14km/h) and the angle of the treadmill (0~8%) were gradually increased to voluntary exhaustion within 6~15 min. Oxygen uptake ($\dot{V}O_2$) and carbon dioxide excretion ($\dot{V}CO_2$) were measured using an automatic open-circuit gas analyzer (System 5, AIC, Tokyo, Japan), and an electrocardiogram (Life Scope 8, Nihon kohden, Tokyo, Japan) was recorded continually throughout the exercise test including rest and recovery periods. If there were any abnormalities in the electrocardiogram and/or BP, the exercise test was promptly stopped, but the subject himself did not request that the exercise cease. BP monitoring, further, was applied to subjects who had no regular exercise habits, nor were over 60 yrs of age, while BP was measured at intervals of 2~3 minutes. Maximal values of $\dot{V}O_2$ and heart rate (HR) measured during a gradually increasing work load exercise test were defined as the voluntary maximal oxygen uptake ($\dot{V}O_2$max) and maximal heart rate (HRmax), respectively, and $\dot{V}O_2$max was adopted finally, according to the criteria for $\dot{V}O_2$max recommended in our previous study (23).

Temperature and relative humidity in the laboratory were 20~27℃ and 50~60%, respectively.

C. Analytical methods for electrolytes and biochemical determinations of blood and urine

Blood and urine specimens were used for measurements of electrolytes (Na^+, K^+, Cl^-, TBA-80, Toshiba, Tokyo, Japan), osmolality (Osmotron-20, Orion Riken Co. Tokyo,Japan), lactate (LA, Lactate test, Boehringer), and biochemical components (creatinine, Cr; albumin, Alb; TBA-80). Urinary lactate concentration (uLA) was measured using the following procedures: immediately after urine sampling, the specimen was deproteinized by 0.6N perchloric acid ($HClO_4$). Further, immediately before analysis the urine specimen was diluted with 0.6N $HClO_4$ 3~5 times, and measured according to the method for analysis of the blood lactate concentration (bLA).

Using the values of urine volume per minute (UV, mℓ/min), serum creatinine (Scr) and urinary creatinine concentrations (Ucr), creatinine clearance (Ccr) was calculated according to the following equation: Ccr (ml/min (1.73 m^2)) = (UV×Ucr×1.73)/(Scr×body surface area (m^2)). Ccr was measured as an indicator of GFR.

Urinary anion gap (uAG) was calculated according to the equation uAG = $(Na^+ + K^+) - (Cl^-)$ in this study.

D. Statistical procedures

The results are expressed as the mean±SD in the text unless otherwise noted. *Student's* paired *t*-test was used to determine significant changes in variables before and after exercise. One-way analysis of variance was used to determine the significant differences in variables between the different age brackets. Statistical analysis of correlation coefficients was performed using Pearson's test. A 95% level of confidence was accepted as significant for all statistical tests.

Results

A. Maximal oxygen uptake ($\dot{V}O_2$max), maximal heart rate (HRmax) and maximal concentration of blood lactate (bLAmax) changes with aging.

Age-associated changes in $\dot{V}O_2$max, HRmax, and bLAmax observed immediately after exhaustive exercise are shown in Fig. 1. $\dot{V}O_2$max and HRmax lowered with age, even though $\dot{V}O_2$max at 15 yrs of age had a tendency to be lower than that at 20 yrs of age. A peak of bLAmax was obtained at 25 yrs old, but thereafter, lowered with age.

B. Effects of aging on the changes in Ccr before and after exhaustive exercise

After the division into three age brackets, under 20 yrs, from 20 to 39 yrs, and over 40 yrs of age, the distribution of Ccr was compared before, immediately after, 30 and 60 min after an exhaustive treadmill run. No significant differences in mean resting Ccr among the three age brackets were found. The greatest reduction of Ccr was indicated immediately after exhaustive exercise in every age bracket, and recovered to the resting level from 30~60 min afterwards. With less broader age brackets, subsequently, the change in Ccr before and immediately after exercise is shown in Fig. 2, and effects of aging on the change were investigated. Resting Ccr in a teenager was significantly lower than that at 20~30 yrs of age. The resting Ccr of those over 45 yrs had a tendency to decline with age. The

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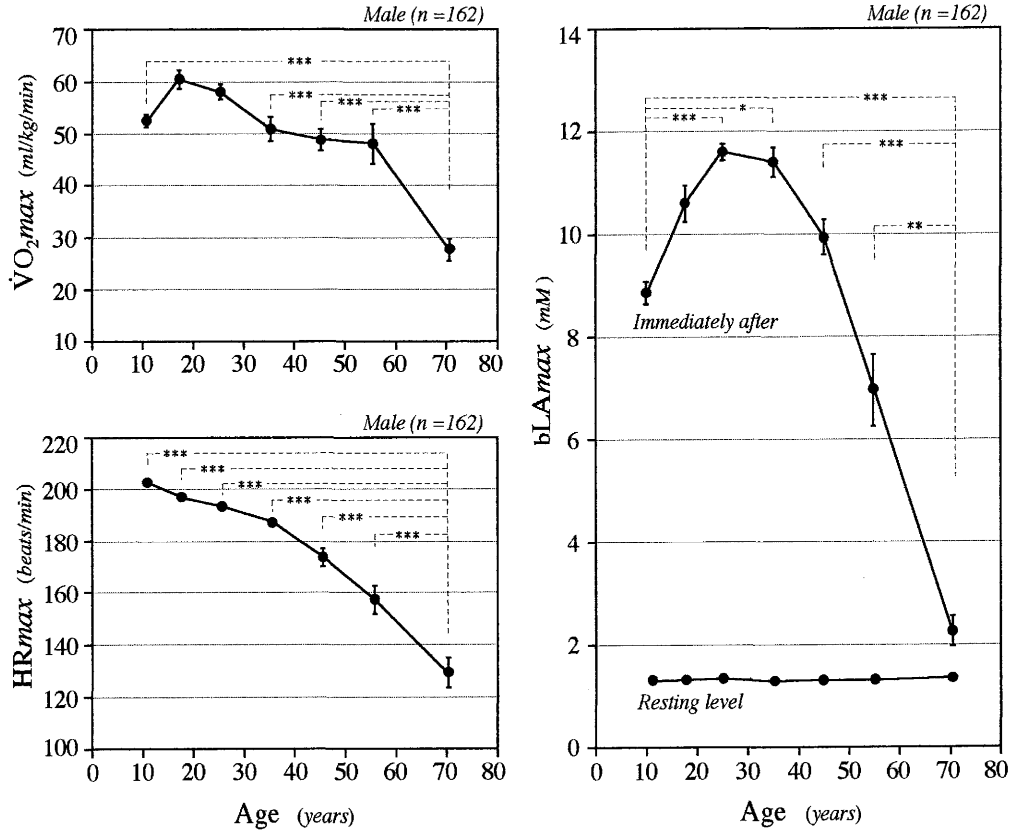

Fig. 1 Age-related maximal oxygen uptake ($\dot{V}O_2max$), maximal heart rate (HRmax), and maximal concentration of blood lactate (bLAmax) measured immediately after an exhaustive treadmill run.
Figures are means±SE ($\bar{\chi}$±SE). Significance of differences between two values measured: *$p<0.05$; **$p<0.01$; ***$p<0.001$.

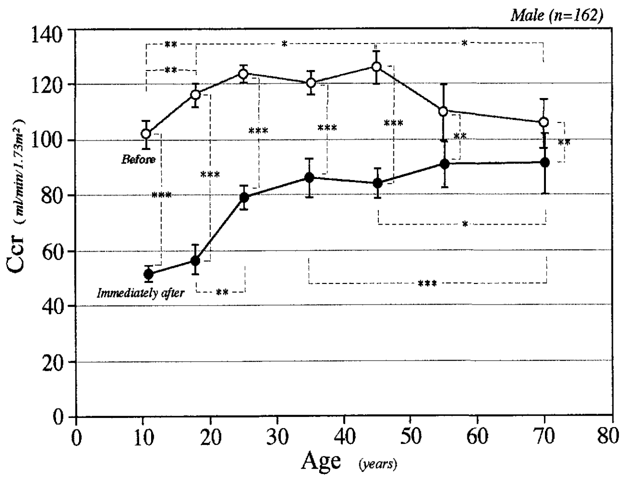

Fig. 2 Effects of aging on the changes in creatinine clearance (Ccr) before and immediately after an exhaustive treadmill run.
Ccr was measured as an indicator of the glomerular filtration rate (GFR). Figures are means±SE ($\bar{\chi}$±SE). Significance of differences between two values measured: *$p<0.05$; **$p<0.01$; ***$p<0.001$.

younger the subjects, the greater the reduction of Ccr after the exercise, with over 55 year olds showing a smaller reduction, though it was significant. To investigate the reason for the age-associated differences in Ccr responses to exhaustive exercise, relationships between changes in ⊿Ccr with $\dot{V}O_2max$, HRmax, ⊿SBP and bLAmax were analyzed (Fig. 3). The symbol⊿ denotes a net change in the variable between before and immediately after exercise. There are significantly negative correlations between ⊿Ccr and the other measurements in all. The greater the reduction of Ccr (⊿Ccr), the higher the $\dot{V}O_2max$, HRmax, ⊿SBP and bLAmax.

C. Effects of aging on urinary albumin excretion (UAE) after exhaustive exercise

The distribution of UAE in the different age brackets before, immediately after, and 30/60 min after exhaustive exercise is shown in Fig. 4. Values of UAE after exercise were spread more widely, and the actual values were converted into logarithmic (log) value. Resting UAE was significantly higher in those over 40 yrs of age than those under 20 yrs or 20~39 yrs of age. Thirty minutes after exercise, UAE remarkably increased in every age bracket. In particular, there was a notable increase of UAE in the under 20 yrs of age group. Sixty minutes after exercise, UAE gradually recovered to the pre-exercise level, although the distribution of value was still broad. The greatest influence of exhaustive exercise on UAE was observed at 30 min af-

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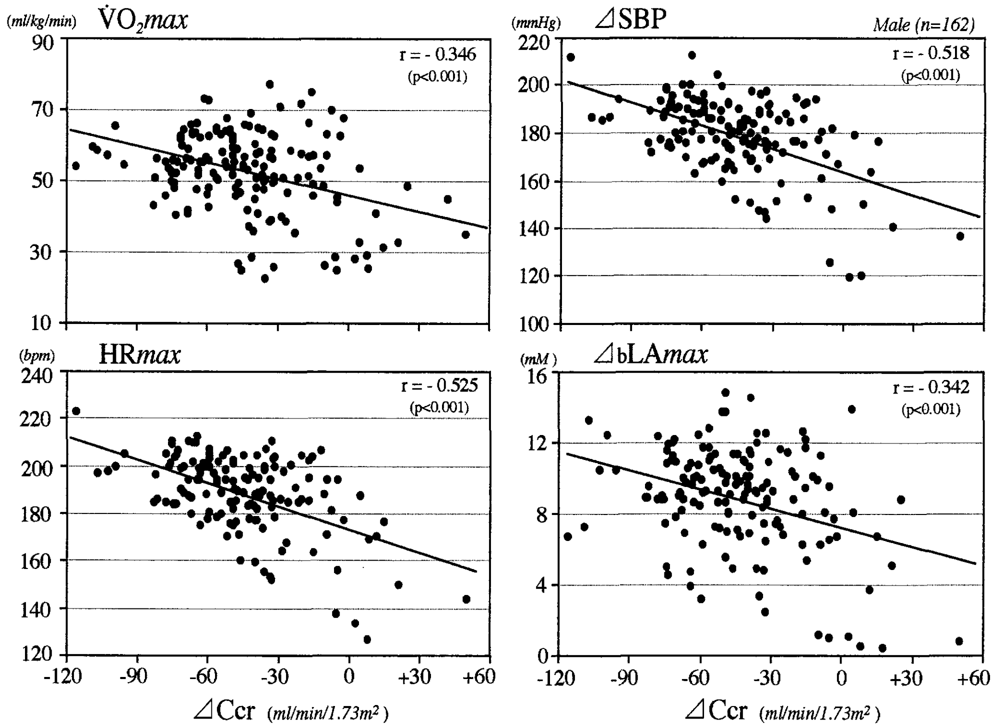

Fig. 3 Relationships between ⊿Ccr with $\dot{V}O_2$, HRmax, ⊿SBP and ⊿bLAmax.
Symbol ⊿ denotes a net change in the variable between pre- and immediately post-exercise.

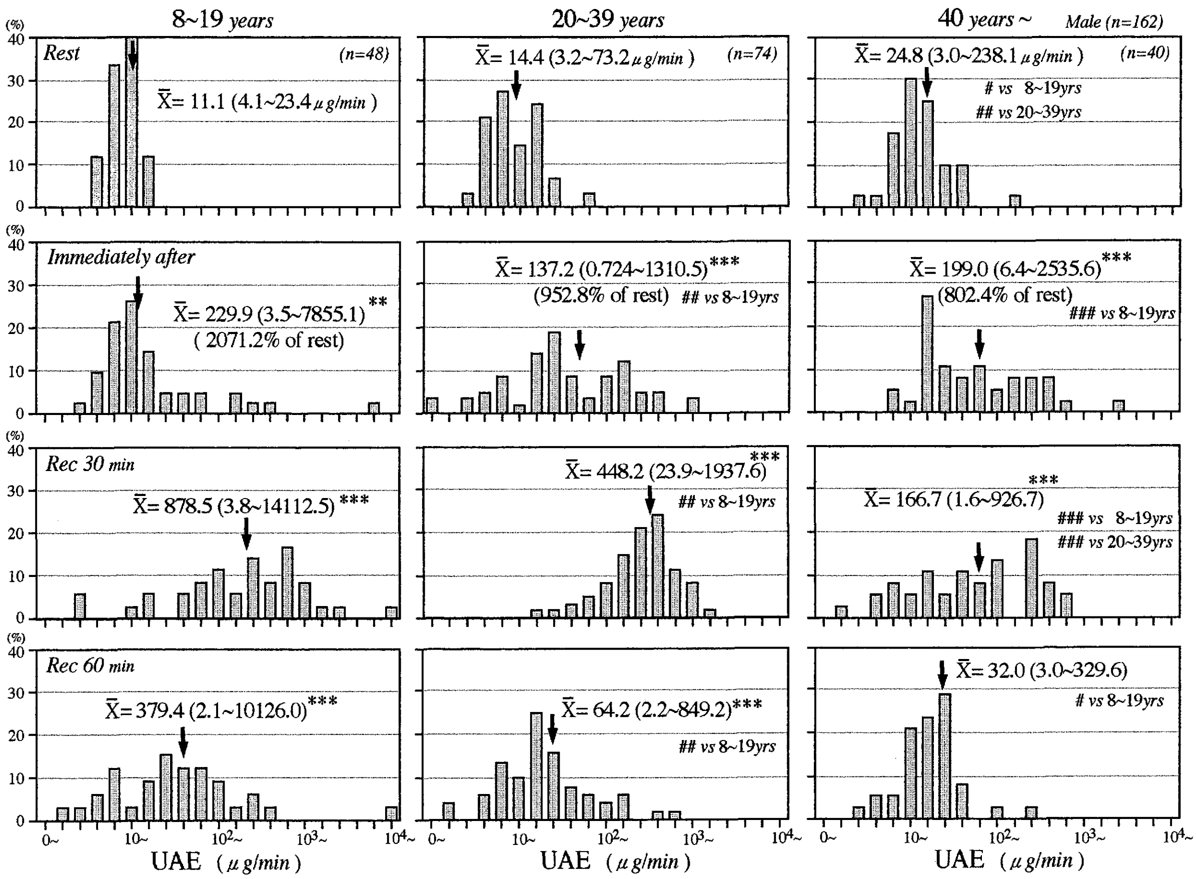

Fig. 4 Effects of aging on the urinary albumin excretion (UAE) after exhaustive treadmill run.
UAE (μg/min) was converted into a logarithm (log), since actual values were distributed with a rather wide spread. Significance of differences compared to resting levels: $^{**}p<0.01$, $^{***}p<0.001$, while also comparing the corresponding values for <20 yrs and 20~39 yrs, respectively: # <0.05, ## <0.01, ### <0.001.

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ter exercise. Therefore, the value of UAE at rest was subtracted from the value of UAE at 30 min after exercise, and this is defined as $\triangle UAE_{rec30\ min}$. The value of $UAE_{rec30\ min}$ was converted to a logarithm, and is shown with less broader age brackets in Fig. 5. $\triangle UAE_{rec30\ min}$ was significantly lower at a mean age of 12.9 (~15) yrs than mean age of 17.4 (16~19) yrs. The peak of $\triangle UAE_{rec30\ min}$ was at 16~19 yrs of age, and gradually declined with age.

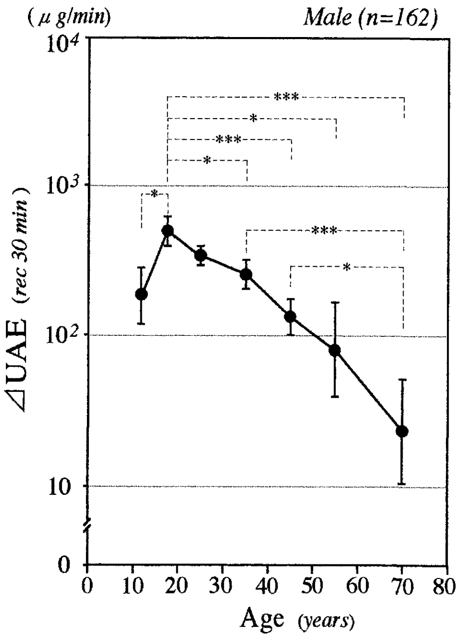

Fig. 5 Effects of aging on the urinary albumin excretion at 30 min ($\triangle UAE_{rec30\ min}$) after an exhaustive treadmill run.
Subtracting the value of UAE at rest from the value of UAE at 30 min after exercise, gives $\triangle UAE_{rec30\ min}$. The value of $\triangle UAE_{rec30\ min}$ was converted to a logarithm. Significance of differences between two values measured: *$p<0.05$; **$p<0.01$; ***$p<0.001$.

D. Relationships between excretions of albumin, electrolytes and organic anions into urine after exhaustive exercise

The greatest influence of exhaustive exercise on urinary excretions of albumin, electrolytes (Na^+, K^+, Cl^-), and an organic anion (uLA^-) was observed at 30 min after cessation of exercise. Significant decreases in the excretion of Na^+, K^+ and Cl^- and an increase in that of LA^- into urine were observed, even though urine volume (UV) increased significantly. Consequently, urine osmolality significantly decreased at 30 min after exhaustive exercise. The younger the age, the greater the changes in these variables, and the reduction in the excretion of Cl^- was particularly remarkable compared with that of sodium. On the other hand, a significant negative coefficient of correlation ($r=-0.722$, $p<0.001$) was obtained between urinary concentrations of Cl^- and LA^-. Relationships between UAE with LA excretion (ULAE) and UCl excretion (UClE) are represented in Fig. 6. A highly positive correlation ($r=0.819$, $p<0.001$) was found between UAE and ULAE. There was, conversely, a negatively exponential correlation between UAE and UClE, and the coefficient of correlation was $r=-0.624$ ($p<0.001$).

Urinary AG (uAG) may reflect changes in unmeasured anions in urine. In this study, uLA, one of the anions in urine, was measured. Using the urinary concentrations of Na^+, K^+ and Cl^- measured at 30 min after exhaustive exercise, the coefficient of correlation between $uAG_{rec30\ min}$ and $uLA_{rec30\ min}$ was analyzed, and is shown in Fig. 7 (I). An extremely high coefficient of correlation ($r=0.914$, $p<0.001$) was indicated between $uAG_{rec30\ min}$ and $uLA_{rec30\ min}$.

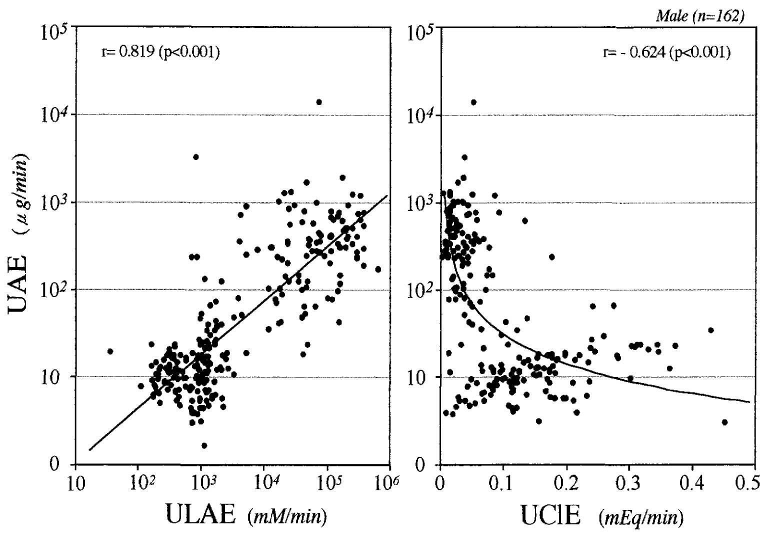

Fig. 6 Relationships between UAE with ULAE and UClE before and after an exhaustive treadmill run.
UAE, urinary albumin excretion; ULAE, urinary lactate excretion; UClE, urinary Cl excretion.

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The greater part of the increase in uAG originated from an increase of lactate excretion into urine. Subsequently, the relationship between bLA and uLA was investigated. The kinetics of the lactate concentration after exhaustive exercise is, however, different in blood and urine. A peak in the blood lactate concentration (bLAmax), as well as in the urinary concentration of LA (uLAmax) was observed immediately after, and 30 min after exercise, respectively. Therefore, we matched bLA and uLA as follows; bLA at rest vs. uLA at rest, bLA immediately after exercise (bLAmax) vs. uLA 30 min after exercise (uLAmax), and bLA 30 min after exercise vs. uLA 60 min after exercise, respectively. The relationship between bLA and uLA concentrations is shown in Fig. 7 (II). This figure indicates that when bLA reached over 4.0 mM, the uLA concentration gradually increased. However, both lower excreted uLA group (L-uLA) and higher excreted uLA group (H-uLA), which located under the lower limit of the 95% confidence line ($\bar{\chi}-1.96$SD) and over the upper limit ($\bar{\chi}+1.96$SD), respectively, are also observed in spite that bLA was over 10 mM in both groups.

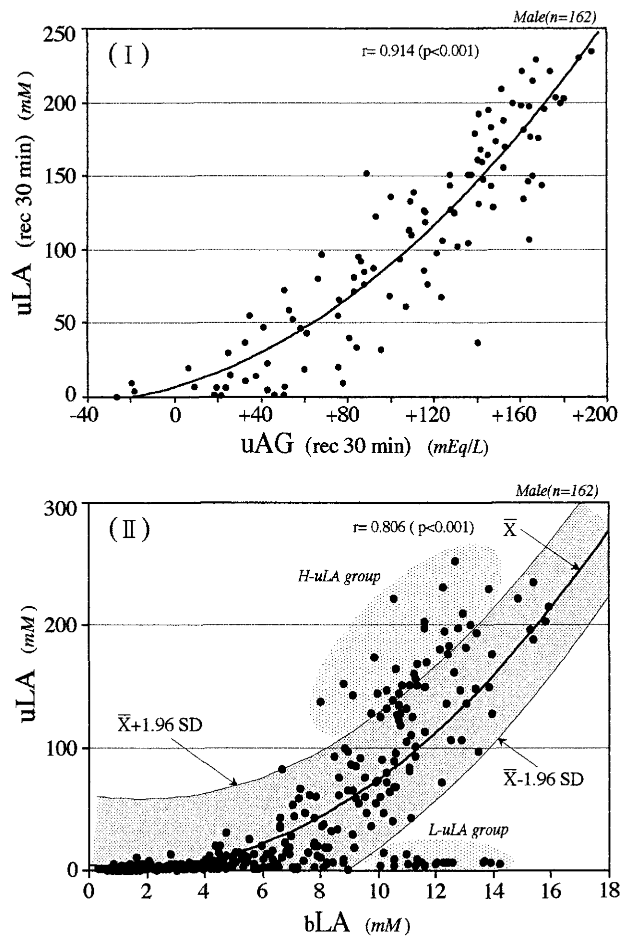

Fig. 7 Relationships between $uAG_{rec30\ min}$ and $uLA_{rec30\ min}$ (upper panel (I)), and between bLA and uLA (lower panel(II)).

$uAG_{rec30\ min}$, urinary anion gap at 30 min recovery was calculated according to the equation as $uAG=(Na^{+}+K^{+})-Cl^{-}$; $uLA_{rec30\ min}$, urinary lactate concentration at 30 min recovery; uLA, urinary lactate concentration; bLA, blood lactate concentration. In the lower panel (II), bLA and uLA were matched as follows; bLA at rest vs. uLA at rest, bLA immediately after exercise (bLAmax) vs. uLA 30 min after exercise (uLAmax), and bLA 30 min after exercise vs. uLA 60 min after exercise, respectively.

L-uLA and H-uLA groups encircled with a net pattern indicate that uLA are shown under the lower limit of, and over the upper limit of 95% confidence line, respectively, in spite of the bLA reaching over 10 mM.

Discussion

The present study was conducted to examine the effects of age on changes in renal functions such as the glomerular filtration rate (Ccr), and excretion in urine of albumin (UAE) and electrolytes after exhaustive exercise in healthy males.

HRmax declined linearly with age from 8 to 80 years, even though peaks of $\dot{V}O_2$max and bLAmax were observed at the mean ages of 17.4 and 22.9 yrs, respectively. Both $\dot{V}O_2$max and bLAmax increased until the age when peaks of these variables occurred, and thereafter lowered with aging. Aerobic ($\dot{V}O_2$max) and anaerobic work capacity (bLAmax) were significantly lower in younger subjects, even though these subjects compelled themselves to reach an exhaustive state which was shown to be an adequately higher level of HRmax. This might be due to underdeveloped muscle mass in these younger subjects. Decreases in $\dot{V}O_2$max and bLAmax after their respective peaks may be a physiological phenomenon associated with aging. Reports on $\dot{V}O_2$max reduction with aging (6, 18, 23, 24) are plentiful. The age-associated reduction in $\dot{V}O_2$max and bLAmax is thought to be due to a reduction of muscle mass, a decrease in muscle mitochondria as well as an alteration in mitochondrial composition (6, 9, 17) and decreases in enzyme activities representing aerobic energy metabolism (malete dehydrogenase, succinate dehydrogenase), and also some of the anaerobic enzymes (creatine phospokinase, lactate dehydrogenase) in skeletal muscle (20). However, the reason for the decrease in HRmax with age is still unclear.

Ccr was measured as an indicator of GFR, which is one of the renal functions. Resting Ccr levels in subjects below 17.4 yrs and over 53.6 yrs of age were significantly lower compared to those in subjects from 20 to 49 yrs of age. It has been known formerly that GFR and effective renal plasma flow (ERPF) decrease with aging (5). The lower Ccr in younger subjects in this study might be caused by underdeveloped renal mass and function. The reduction in renal function (Ccr) at over 50 yrs of age might be due to a decrease of renal size, and eventually, a reduction in the number of glomeruli, resulting in a reduced renal mass and function (2). Bax, et al (2) also suggested that the age-related changes in renal size and function were ac-

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celerated in cases of more severe atherosclerosis with aging. The greatest reduction of Ccr was found immediately after, and recovered to the pre-exercise level within 30~60 minutes after exhaustive exercise in all the age groups. Age-associated changes in net reduction of Ccr (⊿Ccr) between pre- and immediately post-exercise are shown in Fig. 3. The age-associated change in ⊿Ccr presented a reverse mirror image of that in $\dot{V}O_2max$. The greatest decrease in Ccr after exercise was observed at a mean age of 17.4±1.4 yrs, and thereafter the ⊿Ccr gradually became smaller, although significant. Our previous study (25) indicated a high coefficient of correlation ($r=0.773$, $p<0.001$) between creatinine clearance (Ccr) and renal blood flow (RBF) using radionuclide angiography with ^{99m}Tc-phytate after exhaustive exercise in healthy humans. According to our previous study (25), the remarkable decrease in Ccr shown in younger subjects might be caused by RBF reduction. Considering that the greater the reduction of Ccr (⊿Ccr), the higher the $\dot{V}O_2max$ and bLAmax indicated in this study, it was thought that the higher the $\dot{V}O_2max$ and bLAmax, the greater the blood flow into exercising muscles, and consequently renal blood flow was reduced.

The resting UAE level (24.8 μg/min) in those over 40 yrs of age was significantly higher than that in both the under 20 yrs (11.1 μg/min) and 20~39 yrs (14.4 μg/min) of age groups (Fig. 4). Albuminuria is a marker of early atherosclerosis (12). An increased UAE is associated with an unfavorable cardiovascular risk profile (7), but its pathogenesis is currently unknown. An aggravation of atherosclerosis with aging may be the reason for the significantly higher level of resting UAE observed in the over 40 yrs of age group, even though no other markers of atherosclerosis were measured in this study. There was no difference in resting blood pressure level in those over 40 yrs of age compared to that in the younger subject groups.

The highest increase in UAE was observed 30 min after exhaustive exercise in every age group. In particular, the peak of $⊿UAE_{rec30\ min}$ was shown in the 16~19 yrs of age group, and gradually declined with age (Fig. 5). Changes in charge and/or size selective permeability in the glomerular basement membrane (GBM) are thought to be one of the causes of proteinuria (1). Several studies on exercise induced-proteinuria have been done (14, 16, 22). Exercise induced-proteinuria (EIPU) is related to the intensity of exercise, and frequently occurs after exercise with an intensity greater than 80%$\dot{V}O_2max$ (22). The defining feature of EIPU is a mixed glomerular and tubular type of proteinuria, which contains medium to large molecular weight proteins such as IgG, IgA, and albumin, and lower molecular weight proteins (LMWP) such as α_1 microglobulin (α_1 M) and β_2 microglobulin (β_2 M). The mechanism for EIPU has been investigated extensively (14, 16, 22). EIPU was accompanied by reductions in RBF and GFR, and by increases in plasma noradrenaline (pNorad) and plasma angiotensin II (pA II) concentrations. Conversely, it has been reported that the intravenous infusion of Norad or A II produced proteinuria (3, 11), and the oral administration of the angiotensin-converting enzyme inhibitor (ACE-inhibitor) reduced proteinuria in patients with nephropathy (26). From these findings, exercise-induced modifications of renal hemodynamics and the glomerular filtration fraction (FF), as well as activations of the renal sympathetic nerve and the renin-angiotensin (RA) system, have been thought to directly or indirectly increase the permeability of the glomerular capillary membrane to proteins (3, 11, 15). We observed, however, remarkable excretions of albumin and β_2 M into urine after maximal exercise, although the increase in pA II was inhibited by an oral administration of 50 mg of the ACE inhibitor (Captopril) in eight healthy males 30 min prior to exercise (unpublished data). Furthermore, the mechanism for the occurrence of LMWP such as α_1 M and β_2 M after maximal exercise is, however, not explained by the mechanisms mentioned above (3, 11, 15). Sumpio, et al. (19) have shown that high- and low-molecular-weight proteins are mostly, if not totally, reabsorbed by the proximal tubules. Poortmans, et al. (16) and Montelpare, et al. (14) indicated that post-exercise proteinuria was transient, and related to blood acidity changes induced by strenuous exercise. Moreover, Poortmans, et al. (16) identified an exercise-induced impaired site of the S1-S2 segments in the proximal tubule, and concluded that strenuous exercise-induced albuminuria may be linked to the increased glomerular membrane permeability, while the increased excretion of low molecular weight proteins may indicate renal tubular dysfunction.

Based on previous studies (3, 11, 14, 16), we investigated relationships between urinary excretion of electrolytes and lactate (ULAE) with albumin excretion into urine (UAE) after exhaustive exercise in this study. A highly positive correlation ($r=0.819$, $p<0.001$) was indicated between UAE and ULAE (Fig. 6). Conversely, the coefficient of correlation between UAE and UClE was highly negative ($r=-0.624$, $p<0.001$). In contrast, it was shown that increases in uLA originated from an elevation of bLA after exhaustive exercise (Fig. 7 (I)). This quadratic regression curve shows that uLA gradually increases from the level of bLA when greater than 4mM. A remarkable reduction in Cl^- concentrations compared to that of Na^+ in urine 30 min after exercise may be understood to compensate for an increase in the urinary anion gap (uAG), which was the greater part of the increase in uAG which originated from an increase in lactate excretion into urine. As shown in Fig. 7 (II), both lower and higher excreting uLA groups, L-uLA and H-uLA, which are located under the lower limit of the 95% confidence line ($\bar{\chi}-1.96SD$) and exceed the upper limit ($\bar{\chi}+1.96SD$), respectively, were observed in spite that the bLA reached 10 mM in both groups. The urinary Cl^- concentration in L-uLA group was signifi-

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cantly higher than that in H-uLA, and UAE in L-uLA was significantly low compared to that in H-uLA. Increased levels of H^+ in the blood stream after exhaustive exercise were considered to be the same because the bLA level in the L- and H-uLA groups was almost the same (over 10 mM). Nevertheless, the urinary excretion level of LA was different in the L- and H-uLA groups. The more the uLA excretion, the more the urinary excretion of albumin. It is thought that the excess amounts of lactic acid and pyruvic acid produced by strenuous exercise were filtered in the glomerulus, not reabsorbed in proximal tubules (4) and preferentially excreted into urine to normalize the acid-base balance disturbed by exercise. The precise mechanisms for the association between enhanced Cl^- reabsorption and inhibited reabsorption of lactic acid, albumin and lower molecular weight proteins (not measured in this study) at proximal tubules are unclear.

Conclusion

Reduction of Ccr and an increase in UAE after exhaustive exercise dwindled, while resting Ccr decreased and UAE increased with age. Closed relationships among the excessive $\dot{V}O_2$max and bLAmax and an increase in UAE, as well as a reduction in Ccr were noteworthy. It may be that the effects on the kidney lessen due to a decrease in energy production during exercise with aging.

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