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JPFSM: ***Regular Article***

Regular exercise history as a predictor of exercise in community-dwelling older Japanese people

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Abstract A physically active lifestyle is important across the entire life span. However, little is known about life-long participation in regular exercise among older people. The purpose of the present study was to describe regular exercise throughout a person's lifetime and evaluate the impact of exercise earlier in life on participation in exercise at age 60 and over. The participants were 984 community-dwelling older people aged 60 to 86 years. Each participant's life was divided into five age categories: 12-19, 20-29, 30-39, 40-59, and 60 years and over. The association between exercise at an earlier age and that at 60 years and over was assessed using logistic regression analysis adjusted for potential confounders. Men had exercised throughout their lives more than women. Among women, participation in exercise during their 20s and 30s showed a sharp decline. The preference for exercise differed according to age and gender. Among men, the most common patterns of exercise throughout life were exercise during all the age categories, and starting exercise at age 60 and over; whereas in women the most common pattern was no exercise at all. The adjusted odds ratio of exercise at 40-59 years for exercise at age 60 and over was 5.85 (95% confidence interval: 3.82-8.96) among men and 6.89 (4.23-11.23) among women. Regular exercise in the younger age categories affected exercise at age 60 and over among men, but not among women. Regular exercise at 40-59 years was a strong predictor of exercise at 60 years and over in both men and women.
Keywords : regular exercise, older people, life course, random sampling data

Introduction

Physical activity is an important health behavior across the course of one's life. The benefits of physical activity in preventing health decline and physical function loss have been demonstrated, especially for frail and aged people[1]. The Ministry of Education, Culture, Sports, Science and Technology in Japan reported that the participation rate of older people in physical activity and fitness has slightly increased in the past decade[2,3]. However, more than 40 % of older people aged 70 years and older did not participate in any exercise during the past year[4]. Insufficient physical activity remains a public health concern among older people in Japan.

Engaging in sports activities in childhood and adolescence is known to predict physical activity in adulthood[5]. A low level of physical activity in early life has been found to predict physical inactivity in adulthood[6]. However, most longitudinal studies have demonstrated that sports activities in early life have an effect on physical activity in young adulthood[5,6]. It remains unclear whether sports activities in early life are associated with physical activity at an older age. Some studies have found that a history of physical activity was associated with current physical activity in older people[7,8]. In an earlier study we found that the experience of exercise in adolescence was associated with a higher level of leisure-time physical activity in middle-aged and elderly Japanese women[9]. However, little basic descriptive data exists on individual variation in participation in exercise throughout the life span and the impacts of early exercise on physical activity in later life among community-dwelling Japanese older people.

The purpose of the present study was to describe regular exercise throughout the life course and evaluate the effect of early exercise on the participation in exercise at the age of 60 years and over.

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Methods

Study population. The investigation is a part of the 4th survey of the National Institute for Longevity Sciences - Longitudinal Study of Aging (NILS-LSA), which is a follow-up study on the causes of geriatric diseases and health problems in older people. The NILS-LSA was based on data obtained from interviews and laboratory examinations of medical, nutritional, psychological, and physical fitness variables. The details of the study can be found elsewhere[10]. The initial survey of the NILS-LSA involved 2,267 men and women aged 40-79 years, including almost 300 men and 300 women for each decade (40s, 50s, 60s and 70s). The participants were gender- and decade age-stratified random samples of the residents of Obu-shi and Higashiura-cho, Aichi Prefecture, in central Japan. The participants were drawn from resident registrations in cooperation with local governments. All subjects lived or had lived at home in the community. The participants in the present study comprised 523 men and 461 women aged 60-86 years. All the NILS-LSA procedures were already approved by the Ethical Committee of the National Center for Geriatrics and Gerontology, and all of the participants signed a written informed consent.

Measures and Procedures. Regular exercise was assessed using a questionnaire and an interview. The questionnaire was based on a questionnaire developed by the Japanese Lifestyle Monitoring Group[11]. The participants were asked for the type, time, frequency and duration of their regular exercise from the age of 12 years to the present with the question "What physical activities or sports have you participated in during these age categories?" The participants reported the types of physical activities and sports they had engaged in from a list of alternatives. These were coded as 1) light activities such as walking, gymnastic exercise and gardening, 2) moderate activities such as brisk walking, dancing and swimming for pleasure, 3) vigorous activities with increased breathing and sweating such as jogging and playing tennis, 4) exhausting activities such as various competitive sports. Frequency of participation was defined as how often they participated in physical activities or sports per week. The duration of each activity was calculated with 1 year as the basic unit. Physical activities or sports that were engaged in for at least 20 minutes, once a week and over 1 year, excluding physical education at school, were defined as regular exercise. Life span was divided into five age categories: 12-19, 20-29, 30-39, 40-59 and 60 years and over. The age categories of 40 and over included more years with reference to previous studies[7,8], showing physical activity to be stable in middle age[12].

If participants engaged in a number of regular exercises during the same period, the exercise with the longer duration was selected. Interviews were performed by trained staff.

Potential confounders, included age, education, marital status (never married, married, separated, divorced and bereaved), annual income (6,500,000 yen or less vs. more than 6,500,000 yen) and chronic conditions including smoking status (never, former and current), self-rated health (excellent, very good, good, fair and poor) and prevalent diseases (hypertension, ischemic heart disease, diabetes, osteoporosis, arthritis and cancer), were investigated using a questionnaire and interview by a physician. Height and weight were measured using a digital scale. Body mass index was calculated by weight divided by height squared (BMI; kg/m^2). Body fat mass was assessed by dual X-ray absorptiometry (DXA; QDR-4500A, Hologic, USA). Work-related physical activity was estimated using the same questionnaire developed by the Japanese Lifestyle Monitoring Group[11]. Work activities were assigned an intensity coefficient of 1.5, 2.5, 4.5 and 7.5 METs (metabolic equivalents) for sedentary work, work done standing or walking, moderately strenuous work and strenuous work, respectively. The work activity scores were calculated by multiplying the intensity coefficients by the total number of minutes spent on the activity over the last 12 months.

Statistical analysis. The statistical significance of the differences in social and health conditions were analyzed by the Cochran-Mantel-Haenszel test for categorical variables and Student's t-test for continuous variables according to participation in regular exercise at age 60 and over. The participation rate in regular exercise was calculated as the percentage of participants who engaged in exercise in each age category. Gender differences in the participation rate in each age category were analyzed using Pearson's chi-squared test. The relationship between regular exercise in the younger age categories and at age 60 and over was evaluated using multiple logistic regression analysis. Both the unadjusted model and the model adjusted for all potential confounders were analyzed. The analyses were performed for men and women separately, as the gender difference in the participation rate in regular exercise was considerable. Statistical testing was performed using the Statistical Analysis System (SAS), release 9.1.3 (SAS Institute Inc. NC, USA). Probability levels of less than 0.05 were considered to be significant.

Results

Table 1 shows the characteristics of the participants by gender according to participation in regular exercise at age 60 and over. The mean age of the study population was 70.0±6.6 years in men and 69.8±6.7 years in women. Age, weight, BMI, annual income, work-related physical activity, smoking, self-rated health, hypertension and arthritis for men; and height, education, work-related physical activity for women were associated with regular exercise at age 60 and over ($p<0.05$).

The participation rates in regular exercise for age categories 12-19, 20-29, 30-39, 40-59 and 60 years and over

Table 1. Charactaristics of the participants according to regular exercise at age 60 and over for men and women

		Men			Women		
		Regular exercise			Regular exercise		
		Yes	No		Yes	No	
		n=342	n=181	*p*-value	n=263	n=193	*p*-value
Age	years	**70.4 ± 6.3**	**69.2 ± 7.2**	**0.048**	69.7 ± 6.4	70.2 ± 7.0	0.503
Height	cm	163.6 ± 5.7	162.7 ± 5.9	0.108	**150.5 ± 5.6**	**149.1 ± 6.2**	**0.010**
Weight	kg	**62.3 ± 9.0**	**59.2 ± 8.3**	**<0.001**	51.8 ± 7.7	51.7 ± 8.7	0.829
BMI	kg/m^2	**23.3 ± 2.8**	**22.3 ± 2.8**	**<0.001**	22.9 ± 3.0	23.2 ± 3.4	0.246
Body fat	%	22.9 ± 4.4	22.5 ± 4.6	0.395	32.4 ± 5.1	32.6 ± 5.5	0.688
Education	years	11.9 ± 2.9	11.7 ± 3.0	0.513	**11.1 ± 2.3**	**10.6 ± 2.5**	**0.033**
Marital status	%			0.097			0.295
Never		0.0	2.2		3.1	3.7	
Married		94.4	91.2		71.7	64.0	
Separation		0.6	0.6		0.4	0.0	
Divorce		0.6	0.6		1.9	4.2	
Bereavement		4.5	5.5		23.0	28.0	
Annual income	%						
6,500,000 yen and higher		**24.8**	**35.2**	**0.013**	25.8	29.4	0.401
Work-related physical activity	METs*min* 10^{-3}	**130.8 ± 135.9**	**170.7 ± 151.7**	**0.002**	**183.0 ± 85.5**	**206.8 ± 109.0**	**0.010**
Smoking	%			**<0.001**			0.910
Never		**24.8**	**20.3**		93.9	94.2	
Former		**58.1**	**47.3**		2.3	2.6	
Current		**17.1**	**32.4**		3.8	3.1	
Self-rated health	%			**0.001**			0.287
Excellent		**6.5**	**0.6**		3.8	5.2	
Very good		**33.3**	**24.7**		21.7	15.6	
Good		**52.2**	**63.2**		65.0	66.2	
Fair		**7.7**	**9.9**		9.1	12.5	
Poor		**0.3**	**0.6**		0.4	0.5	
Prevalent diseases	%						
Hypertension		**44.5**	**31.3**	**0.003**	40.7	41.2	0.921
Ischemic heart diseases		6.2	9.3	0.188	7.2	6.8	0.852
Diabetes		11.5	11.0	0.860	7.2	5.2	0.385
Osteoporosis		1.2	3.3	0.093	16.4	17.2	0.827
Arthritis		**4.4**	**11.5**	**0.002**	11.8	17.2	0.102
Cancer		6.2	6.6	0.859	5.7	9.4	0.136

Continuous variables are presented as means ± standard deviation (SD), and categorical variables are presented as percentages. The differences between groups were analyzed by Student's t-test for continuous variables and by Cochran-Mantel-Haenszel test for categorical variables. Bold represents significant p-value (<0.05). BMI, Body mass index. METs, Metabolic equivalents

are shown Table 2. The percentage of men who had regular exercise was significantly higher than that of women in all of the age categories ($p<0.05$), except for 40-59 years. Among women, a large drop in the percentage reporting participation in exercise was found during the ages of 20-29 and 30-39 years.

The popular type of exercise reported for the different age categories is presented in Tables 3a and 3b. The most popular activities and sports differed both by gender and by age category. Men frequently reported team sports such as baseball and softball up to 40-59 years of age. In women, volleyball was frequently reported up to 30-39 years of age, while dancing and gymnastics exercise were more likely to be reported among those over 20 years of age. At age 60 and over, walking was the most popular exercise among both men and women.

All the possible patterns of participation in regular exercise from age 12 to the present were examined. Thirty-two different patterns were identified (Figure 1). In men, the most common patterns were participation in regular exercise during all the age categories (12.6%) and participation in regular exercise at age 60 and over (12.6%). In women, the most common pattern was no regular exercise in any age category (21.1%), followed by participation in regular exercise at age 40 and over (14.3%).

Table 4 shows that participating in regular exercise at age 60 and over is related to participation in regular exercise across one's life span. The participants who had exercised at younger age categories were more likely to participate in exercise at age 60 and over for both men and women.

The odds ratios (OR) and 95% confidence intervals (CI) for those who regularly exercised at age 60 and over are shown in Table 5. Although, among men, the results of the unadjusted model for the age category 12-19 years was of borderline statistical significance (OR1.42, 95% CI 0.99-2.05), the odds ratio for participating in exercise at age 60 and over was higher for men who had regular exercise during each age category. The highest odds ratio was 4.63 (95%CI 3.07-6.98) among men who had regular exercise at 40-59 years. In women, regular exercise in the earlier age categories did not correlate with exercise at age 60 and over. However, the odds ratio for participating in exercise at age 60 and over was about six times higher among those who had regular exercise at 40-59 years (OR 5.85, 95%CI 3.82-8.96). After adjusting for age (continuous variable), BMI (continuous variable), education (continuous variable), annual income (6,500,000 yen or less/ more than 6,500,000 yen), work-related physical activity (1SD), smoking (never/ former/ current), self-rated health (excellent/ very good/ good/ fair/ poor) and chronic diseases (Yes/ No), the associations remained in both men and women. Regular exercise at 40-59 years was strongly associated with exercise at age 60 and over in both men (OR 5.96, 95%CI 3.72-9.57) and women (OR 6.89, 95%CI 4.23-11.23).

Table 2. Participation rate in regular exercise across the life course

age (years)	Men (n=523) n	Men %	Women (n=461) n	Women %	*p*-value
12-19	311	59.5	198	43.0	<0.001
20-29	173	33.1	29	6.3	<0.001
30-39	155	29.8	62	13.5	<0.001
40-59	233	44.6	203	44.0	0.871
60 and over	342	65.4	263	57.1	<0.001

Numbers and percentages are shown for those who participated in regular exercise divided into five age categories. Pearson's chi-squared test. df=1.

Discussion

The present study described regular exercise throughout a person's life and evaluated the impact of early regular exercise on participation in exercise at age 60 and over.

Previous longitudinal studies suggest that physical activity in early life tracks to later life[5,6]. However, most studies have tracked physical activity from childhood and adolescence to young adulthood and the coefficients re-

Table 3a. Popular types of regular exercise across the life course among men (n=523)

age (years)	1st	%	2nd	%	3rd	%
12-19	Baseball	16.6	Track & Field	11.9	Judo	8.4
20-29	Baseball	11.9	Softball	4.6	Table tennis	4.0
30-39	Golf	7.6	Softball	6.5	Baseball	5.9
40-59	Golf / Walking *	16.1			Softball	7.6
60 and over	Walking	34.4	Brisk walking	18.4	Golf	13.2

Percentages are shown for those who participated in the exercise. *, Both golf and walking share in 1st place with the same percentage.

Table 3b. Popular types of regular exercise across the life course among women (n=461)

age (years)	1st	%	2nd	%	3rd	%
12-19	Volleyball	15.8	Softball	7.8	Table tennis	6.1
20-29	Volleyball	1.7	Dancing	1.3	Tennis	0.9
30-39	Volleyball	3.5	Walking	2.8	Tennis, Dancing or Softball	1.5
40-59	Walking	13.9	Gymnastics exercise	8.7	Dancing	8.5
60 and over	Walking	24.7	Gymnastics exercise	15.4	Brisk walking	9.5

Percentages are shown for those who participated in the exercise.

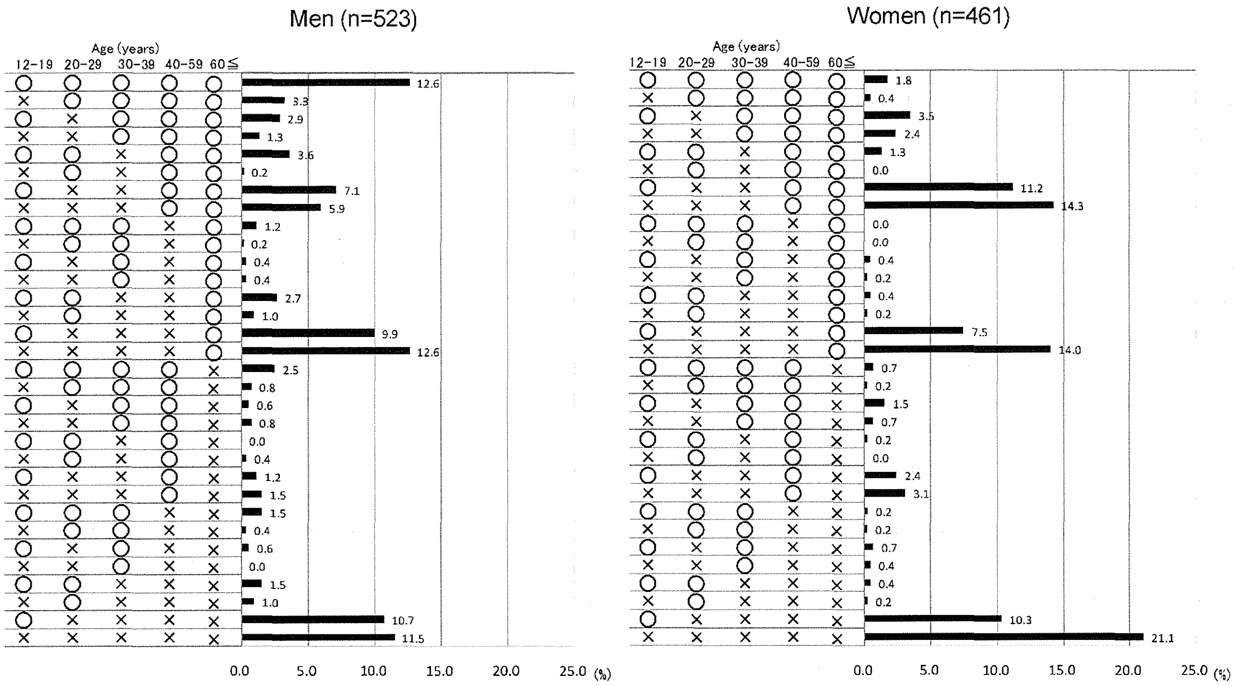

Fig. 1 Participation pattern in regular exercise across the life course for men and women, separately
Regular exercise status: (○) = participants who engaged in regular exercise, (×) = participants who did not engage in regular exercise

Table 4. Distribution of participation in regular exercisre at age 60 and over according to participation in regular exercise across the life course

age (years)	Regular exercise	Men (n=342)		Women (n=263)	
		n	%	n	%
12-19	No	130	61.3	144	54.8
	Yes	212	62.0	119	60.1
20-29	No	213	60.9	244	56.5
	Yes	129	74.6	19	65.5
30-39	No	225	61.4	223	56.0
	Yes	117	75.5	40	64.5
40-59	No	148	51.3	104	40.3
	Yes	194	83.3	159	78.3

Numbers and percentage are shown for those who engaged in regular exercise at age 60 and over.

ported have been only low or moderate[5]. In another study, the correlation between the time points studied was found to weaken over time[13]. Only a few studies have examined whether physical activity in early life tracks to an older age. Retrospective findings that past physical activity predicts physical activity in older people[7,8] can help to explain the positive association between experiences of exercise and physical activity later in life. However, basic descriptive data on individual exercise history throughout life is lacking for the community-dwelling older people in Japan. Assessing life-long regular exercise and the contribution of past exercise experience to engagement in regular exercise later in life are the underlying considerations when promoting an active lifestyle throughout a person's life.

Our finding that men are more physically active than women throughout their lives is partially supported by pre-

Table 5. Odds ratio and 95% confidence interval for those who had regular exercise at age 60 and over

	Model 1				Model 2			
	Men		Women		Men		Women	
	OR	95%CI	OR	95%CI	OR	95%CI	OR	95%CI
Regular exercise								
At 12-19 years of age	1.42	0.99 - 2.05	1.30	0.89 - 1.90	**1.69**	**1.10 - 2.58**	1.06	0.71 - 1.60
At 20-29 years of age	**2.03**	**1.35 - 3.05**	1.43	0.65 - 3.14	**1.87**	**1.21 - 2.90**	1.26	0.55 - 2.87
At 30-39 years of age	**2.02**	**1.32 - 3.09**	1.47	0.84 - 2.58	**2.00**	**1.27 - 3.15**	1.29	0.69 - 2.41
At 40-59 years of age	**4.63**	**3.07 - 6.98**	**5.85**	**3.82 - 8.96**	**5.96**	**3.72 - 9.57**	**6.89**	**4.23 - 11.23**

OR, odds ratio; CI, confidence interval. Model1: unadjusted, Model2: adjusted for age, BMI, education, income, work-related physical activity, smoking, self-rated health, chronic diseases. Bold represents significant p-value (<0.05) vious studies[14,15]. Women may perceive more traditional, social and environmental barriers than men to engaging in exercise[8,15]. For instance, exercise has been considered "not ladylike"[16]. These aspects may in part be responsible for the lower rate of participation in exercise throughout life among women. Furthermore, a large drop in participation in exercise was observed among women in their 20s and 30s. The transition from adolescence to adulthood is a period of general decline in physical activity[17]. Some life changes, such as getting married and having children, affect physical activity in young adulthood in women more than in men[5]. National data in Japan show that the age of first marriage for men was 26.9 years and for women 24.2 years in 1970[18]. The most common age range for giving birth is 20-39 years[19]. After the fourth decade of life, most people's family and job situations seem to be established and stable. Retirement, in turn, tends to increase physical activity[20]. These life events may be associated with regular exercise. Further research on the relationship between life events and exercise is needed to clarify this issue.

The most popular activities and sports changed between the earlier and later age categories; there was also a gender difference in popular types of activities throughout life. Previous studies have reported a high frequency of ball games among men across ages 14 to 31 years[21]. Dance and gymnastics were more popular with women[15,22]. Our finding supports the previous gender difference in the traditional preferences for specific types of exercise. From the perspective of age, team sport activities were common in adolescence and young adulthood, and individual sports in middle age and older. A possible explanation of the shift is that social situations and lifestyle change according to age, for instance, it is more difficult for a large number of adults to get together, whereas individual sports can be performed in one's own time[21]. Individual sports are sometimes labeled lifetime sports[23] and adult-like activities[17]. Previous studies have reported walking and gardening as the most common activities among older adults[24]. To maintain their exercise levels, people may have to choose specific types of exercise as their lifestyles change with aging[25]. We may consider that older people who engage in regular exercise in our study are those who are able to find suitable activities to match their life changes.

In this study, we tracked regular exercise from adolescence to age 60 and over, and described the individual variation in participation in exercise. A number of participants reported participating in regular exercise at some time in their life, although reports of consistent engagement in regular exercise across several decades were scarce. We have already shown cross-sectionally in Table 2 that the prevalence of regular exercise in the 20s and 30s was low. Figure 1 illustrates the findings as individual transitions of regular exercise throughout life. Although the percentage in each pattern was small, and the patterns of exercise frequency seemed to be similar in both men and women, we found that among men the most frequent pattern was participation in regular exercise at all the life stages; whereas among women the most frequent pattern was no regular exercise at all. Results suggest that encouragement and support for older women should be provided by health professionals as well as the community, since participation in exercise may induce a major behavioral change among older women. There may be a need to tailor health promotion messages and interventions according to gender and personal exercise history.

After fully adjusting for confounding factors such as age, BMI, education, annual income, smoking, work-related physical activity, self-rated health, and chronic diseases, both men and women who had participated in regular exercise during 40-59 years of age had a 5 to 7-fold higher rate of participation in exercise at age 60 and over. This result suggests that participation in exercise during 40-59 years of age predicts exercise at age 60 and over. Our findings are in line with those of some previous studies[7,8]. Frändin et al. , who studied age groups from the age of 10 years, found that physical activity during earlier life was not correlated with physical activity at the age of 76, except for the last age period 66-76 years[7]. Other studies also found the last age group to be better predictors than earlier ones[8,26]. The short interval may be one of the causes for the strong relationship between regular exercise at 40-59 years of age and that at age 60 and over. A number of studies have suggested that childhood is usually considered the best time for socialization into physical activity[8], for encouraging physical activity in adults through the developing of habits[25] and for promoting exercise-related feelings of pleasure and joy[7]. Furthermore, sports activities may have an effect on motor and coordination skills that may be of value later in life[21]. We believe that the positive effects of exercise in early life are associated with physical activity in older life. In fact, regular exercise during all the age categories studied affected exercise at age 60 and over among men. However, demographic, psychological, behavioral, social and environmental factors are associated with adulthood participation in physical activity[27]. These multiple factors may decrease the positive effect of earlier exercise at older ages. Health problems were reported to be the most common barrier to increasing physical activity[28]. We found that the effect of regular exercise at 40-59 years of age on participation in exercise at age 60 and over increased among women who had a history of hypertension in the sub-analyses (data not shown). Chronic health problems may also have influenced the motivation for physical activity as a part of clinical care. Our finding that regular exercise during 40-59 years of age was associated with that at age 60 and over was true for a lot of people who had not engaged in regular exercise earlier in their lives. The motivation to engage in regular exercise in the fourth and fifth decades of life may have important implications for promoting increased physical activity in older age.

This study has several limitations. The first limitation is that our study was a retrospective study and the regular exercise data were based on self-reports. Possible memory failure and potential recall bias may have influenced the results. In addition, we were not able to take into account the short-term substitution of one exercise for another as regular exercise was defined as an activity lasting one year. Therefore our study may underestimate regular exercise as an indicator of physical activity. Secondly, social and environment factors, which have been indicated as predictors of physical activity, were not widely examined in our study. Environmental factors are among the important factors promoting participation in physical activity[16]. Recent studies suggested that environmental problems, such as poorly lit streets or noisy traffic, are correlated with inactivity[29]. Further studies are needed to confirm the association between regular exercise and a comprehensive range of factors. Finally, the definition of regular exercise in this study was lower than the well-known recommendation of physical activity for adults by the American College of Sports Medicine[30]. However, we previously found that continuation of regular exercise by the same definition as used in this study was associated with higher muscle strength and power in both elderly men and women[31]. A number of older people are physically inactive. "Tojikomori", being housebound, which has been defined in recent studies as going outdoors once or less than once a week, is a serious concern in relation to older people[32]. Pate et al. suggest that an active lifestyle does not require a regimented, vigorous exercise program[33]. To avoid causing undue stress coming from misconceptions, it may be sufficient just emphasizing to older people the importance of being physically active as opposed to having to maintain a disciplined workout schedule.

The strengths of the present study include a large number of randomized community-dwelling people and regular exercise data tracked from age 12 to 60 years and over. These data provide important information for demonstrating the value of life-long physical activity. The participants had a face-to-face interview by trained staff, which increases the reliability of the answers and reduces missing data in the questions. We were able to take into account essential social and health condition data such as education, smoking and disease as confounders. Our study described individual variation in regular exercise throughout the various stages of a person's life and showed the positive impact of experiences of exercise in earlier life on regular exercise in later life; and thus lays a good foundation for persuading the general population of the importance of maintaining physical activity throughout life.

Conclusion

The present study found that men engaged in regular exercise more than women throughout their lifetime. Exercise preferences differed depending on age and gender. Among women, those reporting no regular exercise were the largest group. Among men, regular exercise earlier in life positively affected regular exercise at age 60 years and over. Regular exercise in middle age markedly increased participation in exercise later in life regardless of social and health conditions among both men and women.

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Imaging of Glucose Uptake During Walking in Elderly Adults

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Abstract: Gait disorders have been identified as one of the most influential physical impairments associated with deterioration in daily living activities among the elderly. A better understanding of the mechanisms responsible for gait disorders is important for developing intervention strategies for the elderly. In recent years, positron emission tomography (PET) and [^{18}F]fluorodeoxyglucose (FDG) have been used to monitor glucose uptake by skeletal muscle during exercise. This review discusses recent studies in which FDG PET has been used to measure muscular glucose uptake, differences between young adults and the elderly in muscular glucose uptake during walking, and the usefulness of FDG PET for determining the effects of exercise intervention in the elderly.

Keywords: FDG, positron emission tomography, aged, gait disorder, skeletal muscle, exercise, physical activity.

INTRODUCTION

Healthy elderly people have less muscle mass, strength, and power production than healthy young people [1-5]. These differences are associated with a slower gait speed, shorter step length, shorter swing phase, and less range of motion at the hip, knee, and ankle joints during walking in the elderly [6-16]. A decrease in walking speed is associated with an increase in the need for assistance with daily living activities [17,18], falls [19-21], and nursing home admission [22]. Many studies have been conducted to identify the characteristics of the gait of the elderly.

Kinesiological studies have found that healthy elderly people carry out locomotor tasks at a level closer to their maximal torque-producing capabilities than young adults [23]. The increase in muscular activation during walking is a potential cause of decreased physical activity [24] because sustained walking may be limited, not by general exhaustion, but by the onset of fatigue in any of the participating muscles. Any decrease in physical activity has adverse effects on physical and psychological functions in elderly people [25,26]. Therefore, local muscle energy expenditure appears to be more important than global expenditure in determining movement and physical activity in the elderly [27].

In recent years, positron emission tomography (PET) and [^{18}F]fluorodeoxyglucose (FDG) has been used to monitor cumulative muscle activity during exercise and to provide images of the spatial distribution of skeletal muscle metabolism [28-32]. PET is a method to detect gamma ray emitted from administered radiochemical compound such as FDG, and therefore a quantitative measurement of the spatial distribution of FDG is available. The purpose of this review is to examine whether FDG PET is useful for studying the gait of the elderly and for developing rehabilitation programs.

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MUSCLE ACTIVITY DURING WALKING IN THE ELDERLY

Winter *et al.* reported that one of the most critical changes with age is a reduction in stride caused by a lower plantar flexor power burst in the terminal stance phase of the gait cycle [11]. Neptune *et al.* suggested that a reduced power burst in the plantar flexor affects swing initiation and trunk progression during the late stance of the gait cycle and trunk stabilization in the early stance of the gait cycle [33]. The reduced power in the plantar flexor redistributes muscle activity and power with aging and is accompanied by increased output of the hip musculature and decreased output of the musculature of the more distal joints. DeVita and Hortobagyi reported that healthy elderly people produced 279% more work at the hip, 39% less work at the knee, and 29% less work at the ankle during the gait cycle compared with healthy young adults [34]. Therefore, advanced age is associated with a redistribution of joint torques and power in which the elderly use their hip extensors more and their knee extensors and ankle plantar flexors less than young adults when walking [34]. The compensatory response to decreased ankle power output appears to emanate from the hip muscles in healthy elderly individuals [15,34] and elderly individuals with a lower extremity disability [35,36]. A recent analysis using a musculoskeletal model showed that the power output of the plantar flexors is of particular importance for maintaining a normal walking pattern because it is able to compensate for many musculoskeletal deficits, including diminished muscle strength in the hip and knee flexors and extensors and increased hip joint stiffness [37].

An increase in the compensatory activity of proximal muscles is associated with an increase in neural stimuli to the muscles involved in walking and enhanced coactivation of the opposing muscles [23,38]. Excessive coactivation increases the metabolic cost of exercise. Mian *et al.* reported that antagonist muscle coactivation is greater in the elderly than in young adults, and that coactivation is moderately correlated with the metabolic cost of walking [39]. The increase in coactivation in the elderly during gait may be a

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compensatory mechanism for joint stiffness and thereby enhance stability [38]. This may be necessary because of low muscle strength and stiffness in the elderly, which would render them less able to recover quickly from a fall or from loss of dynamic stability. These results suggest that rehabilitation or preventive exercise programs should consider focusing on increasing or maintaining plantar flexor activity during walking, which appears critical for maintenance of normal walking mechanics [37]. Accurate measurement of muscle activity during walking is required to develop exercise programs for elderly people who exhibit compensatory responses or coactivation.

GLUCOSE UPTAKE IN SKELETAL MUSCLES DURING WALKING

Several noninvasive modalities have been used to acquire information on skeletal muscle function *in vivo*. Magnetic resonance (MR) imaging techniques are noninvasive and can be used to characterize the motion and mechanics of contracting skeletal muscle *in vivo* [40-42] but cannot be used to measure its metabolic activity. Electromyography (EMG) has been used to evaluate muscle activity, and amplitude-based algorithms have strong associations with metabolic cost. However, some of the elderly are not able to achieve maximal contractions [43], and quantification requires normalization of EMG amplitude to a maximal voluntary contraction EMG amplitude. Moreover, surface EMG is inappropriate for evaluating the activities of deep muscles such as the gluteus minimus. Kinetic analysis has also used to examine muscle activity during walking. However, this technique provides limited information on the etiology of the metabolic cost of walking because it cannot measure isolated synergistic muscular activities.

In FDG PET analysis, FDG is taken up by cells from circulation through glucose transporters 1–4 and is phosphorylated into FDG-6-phosphate by hexokinase, the first enzyme in the glycolysis pathway [44]. Because FDG-6-P is a poor substrate for glucose-phosphate isomerase, which converts glucose to fructose, and a lack of the enzyme for dephosphorylation, FDG-6-P escapes from further metabolism and is trapped within the cells [45], and can be detected using gamma ray emission [46]. Furthermore, FDG facilitates assessment of muscular activity because the half-life of ^{18}F is relatively long (109.8 min) compared with that of other positron-emitting tracers, which makes it ideal for observing cumulative muscle activity over a long period. Its demerits are a transient measurement is impossible. FDG PET can also be used to compare task-specific muscle activity because FDG uptake is closely correlated with exercise intensity [30,47,48]. For instance, Pappas *et al.* reported the results of regression analysis between normalized biceps FDG uptake and the number of repetitions of elbow flexion performed with 2 lb and 10 lb weights. Statistically significant positive correlations were found for both the 2 lb ($r = 0.899$) and 10 lb ($r = 0.958$) weights. The slopes of the 10 lb and 2 lb regression lines were 0.029 and 0.006, respectively. The ratio of the slopes for the 10 lb and 2 lb weights was 4.94, nearly equivalent to a fivefold ratio between the external forces produced by the elbow flexors for these two loads [47].

Oi *et al.* analyzed muscular activity during level walking in healthy young adults using FDG PET [31]. They found that the activity of the lower leg muscles was higher than that of the thigh muscles at self-selected speeds during a 15 min trial. We confirmed their findings in a recent study [32], providing good evidence that FDG PET is an appropriate method for measuring muscle activity during walking and identifying differences in muscle activity between young adults and the elderly during walking [49]. The subjects walked on a treadmill during 50 minutes. All young subjects could walk at the target walking speed of 4.0 km/h. However, all 10 elderly subjects could not walk at the target speed so the walking speed was reduced to achievable levels between 1.86 and 3.54 km/h. FDG (young: 361 ± 21 MBq, elderly: 367 ± 30 MBq) was injected 30 minutes after the start of the walking. From 35–80 minutes after the FDG injection, PET scans of the area from the crista iliaca to the planta were conducted in six overlapping bed positions. The images were reconstructed with a filtered-back-projection algorithm using a second-order low-pass filter with a cutoff frequency of 1.25 cycles/cm. Fig. (**1**) shows representative FDG PET images for a young adult and an elderly. The elderly had significantly increased glucose uptakes in the semitendinosus, biceps femoris, iliacus, gluteus minimus, gluteus medius, and gluteus maximus muscles. FDG uptake ratios between the elderly and young adults for the semitendinosus, biceps femoris, iliacus, gluteus minimus, gluteus medius, and gluteus maximus muscles were 3.02, 3.19, 1.66, 1.64, 3.68 and 3.05, respectively [49]. The elderly exhibited higher glucose metabolism in the hamstrings and hip muscles during walking than young adults. In contrast, distal muscles such as the planter flexors had lower FDG uptake ratios in the elderly compared with young adults, although the difference was not statistically significant. Of the distal muscles, the soleus had the lowest FDG uptake ratio (0.47). These findings on cumulative muscle activities during walking support previous kinesiological studies [11,34] and suggest that efficient muscle activity of the hamstrings or hip muscles during walking improves walking efficiency and results in a normal walking pattern in the elderly. Intervention studies are required to confirm this hypothesis.

FDG PET AS A TOOL FOR EVALUATING INTERVENTION EFFECTS

Walking exercise is attractive to elderly people because it is familiar and more convenient than many other sports and recreational activities [50,51]. Intervention studies have shown that strength or endurance training can improve measures of gait such as walking speed in elderly people [52-56]. It also improves physical fitness, particularly cardiovascular fitness and cognitive functions [57]. A better understanding of the effects of muscle activity during walking by exercise interventions may facilitate the development of targeted exercise programs.

Evaluation of a Walking Aid Using FDG PET

We previously described muscle activity in the elderly with or without a walking aid using FDG PET [58]. The walking aid involved a robotic stride assistance system (SAS) (Honda R & D Co. Ltd, Wako, Japan), which con-

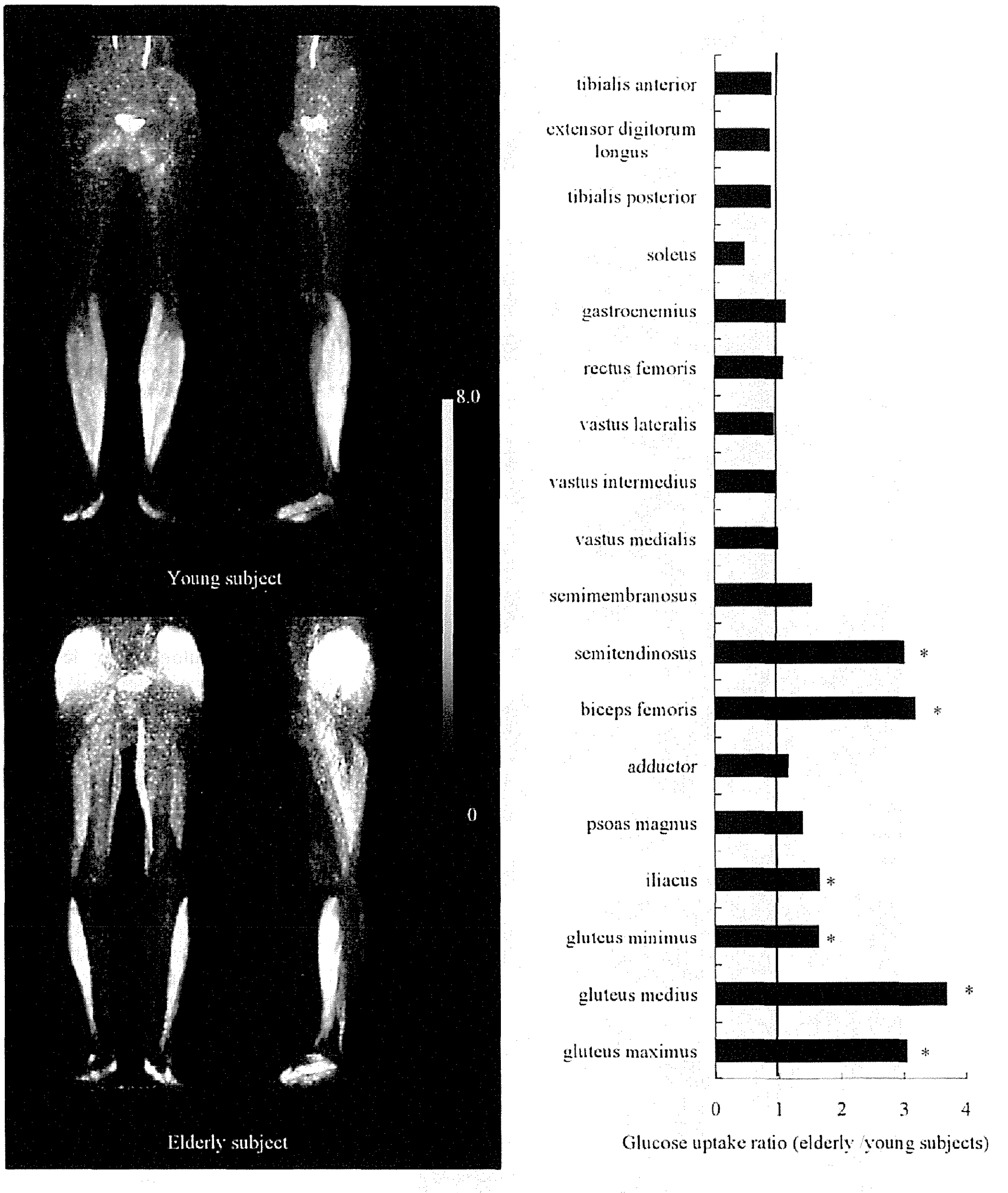

Fig. (1). FDG PET images taken after walking in young and elderly subjects.
$*p<.05$, $**p<.01$
In left FDG PET images, the above and below panels show projection images in young and elderly subjects, respectively. The elderly had significantly increased glucose uptakes in the semitendinosus, biceps femoris, iliacus, gluteus minimus, gluteus medius, and gluteus maximus muscles. The white color at the center of the pelvis resulted from accumulation of FDG in the bladder. Right bar chart shows FDG uptake ratios between the elderly and young adults in the lower skeletal muscles.

trolled the walk ratio (stride length/cadence) and provided supportive power to the thigh during walking [32]. Additional supporting information about the SAS may be found in the online version of our previous article (Movie S1) [59].

Fig. (2) shows representative FDG PET images taken after walking with or without the SAS. Glucose utilization in the lower-extremity muscles was evident after walking. There was no significant difference in the FDG uptakes of the lower skeletal muscles with or without the SAS, but the walk ratio, which was lower than the optimized walk ratio, and walking speed were improved by the SAS. These results suggest that the SAS can facilitate efficient walking patterns in respect of muscle activity. The improved walk ratios of elderly subjects may have increased the torque of their hip

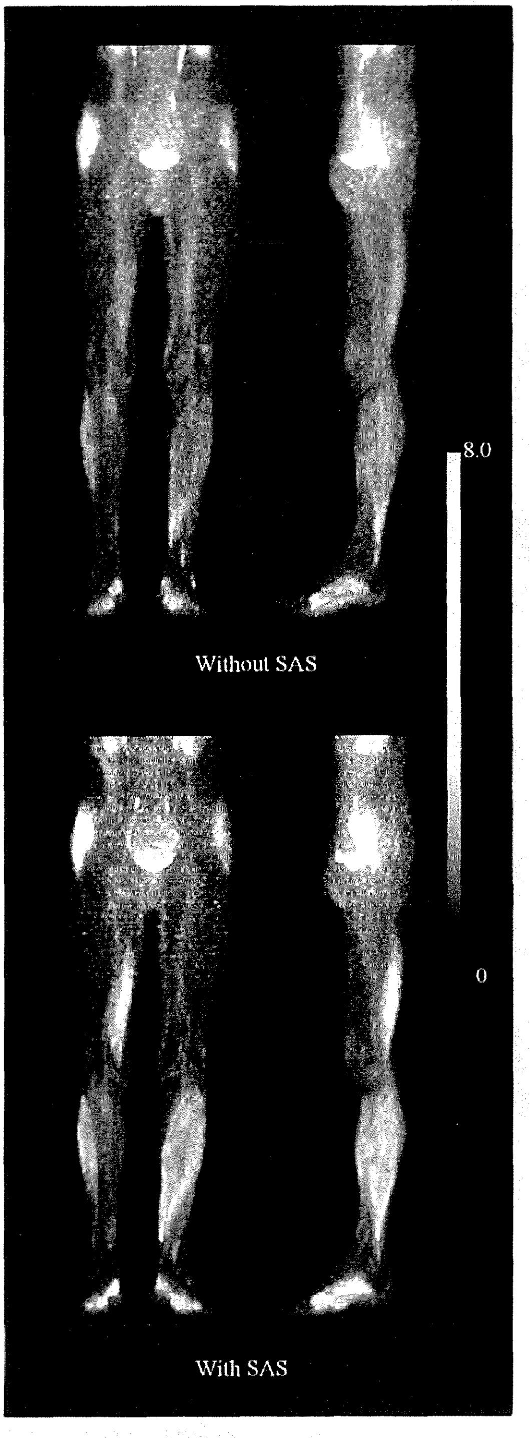

Fig. (2). FDG PET images taken after walking without or with the SAS.

FDG PET images taken after walking without or with the SAS were shown above and below panels, respectively. There was no significant difference in the FDG uptakes of the lower skeletal muscles with or without the SAS, although the walk ratio and walking speed were improved by the SAS.

joints through the assistance provided by the SAS to the thigh. Therefore, the increased walk ratio was elicited without activating lower-extremity muscle activity. As these findings were revealed by FDG PET analysis, this technique may be useful for evaluating other walking aids or rehabilitation tools.

Evaluation of Exercise Intervention Using FDG PET

The purpose of our next study was to assess the effects of a walking program for the elderly using the SAS. Fifteen subjects participated in a three-month walking program using the SAS, involving two 90 min supervised sessions per week. For FDG PET analysis of the walking program, subjects walked for 50 min at a comfortable speed on a circular indoor walking track without the SAS. Fig. (3) shows representative FDG PET images taken before and after the exercise intervention [59]. FDG uptake by the gluteus minimus, gluteus medius, and rectus femoris was significantly lower after the intervention than the one before it, although walking speed during FDG PET measurements increased after the intervention. In contrast, the lower distal muscles such as the medial gastrocnemius and soleus showed higher FDG uptakes after the intervention than those before it, although the difference was not statistically significant.

The SAS automatically lends horizontal force to the thigh to facilitate an optimal walk ratio and the SAS may help the elderly to learn how to use their muscles more efficiently. The consecutive stimuli provided by the SAS may help the elderly to adopt an efficient walking pattern. This study suggests that FDG PET is an appropriate tool for identifying intervention effects in terms of the glucose metabolism of muscles.

FUTURE DIRECTIONS

FDG PET analysis is noninvasive and is useful for studying cumulative muscle activity during exercise. However, because it cannot be automated and the measurement cost is high, it is difficult to apply to large samples or in clinical or community care settings. As a methodological issue of FDG PET, a kinetic analysis has a possibility to give us more quantitative information such as glucose transporter and hexokinase, although the kinetic analysis requires arterial blood sampling and it is a demerit of this approach. Clarification on whether increased muscle metabolism in the elderly is associated with muscle weakness, neuromuscular incoordination, kinesiological factors, daily living activity level, or dysfunctional physiological factors is required to facilitate targeted intervention. Future studies are required to develop a FDG PET system for analysis of muscular activity and to identify relationships between glucose uptake of muscles used quantitative FDG PET analysis and physical or behavioral variables.

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Ethical Approval: The ethics committee of the Tokyo Metropolitan Institute of Gerontology approved the protocol for all our researches which were referred by present paper.

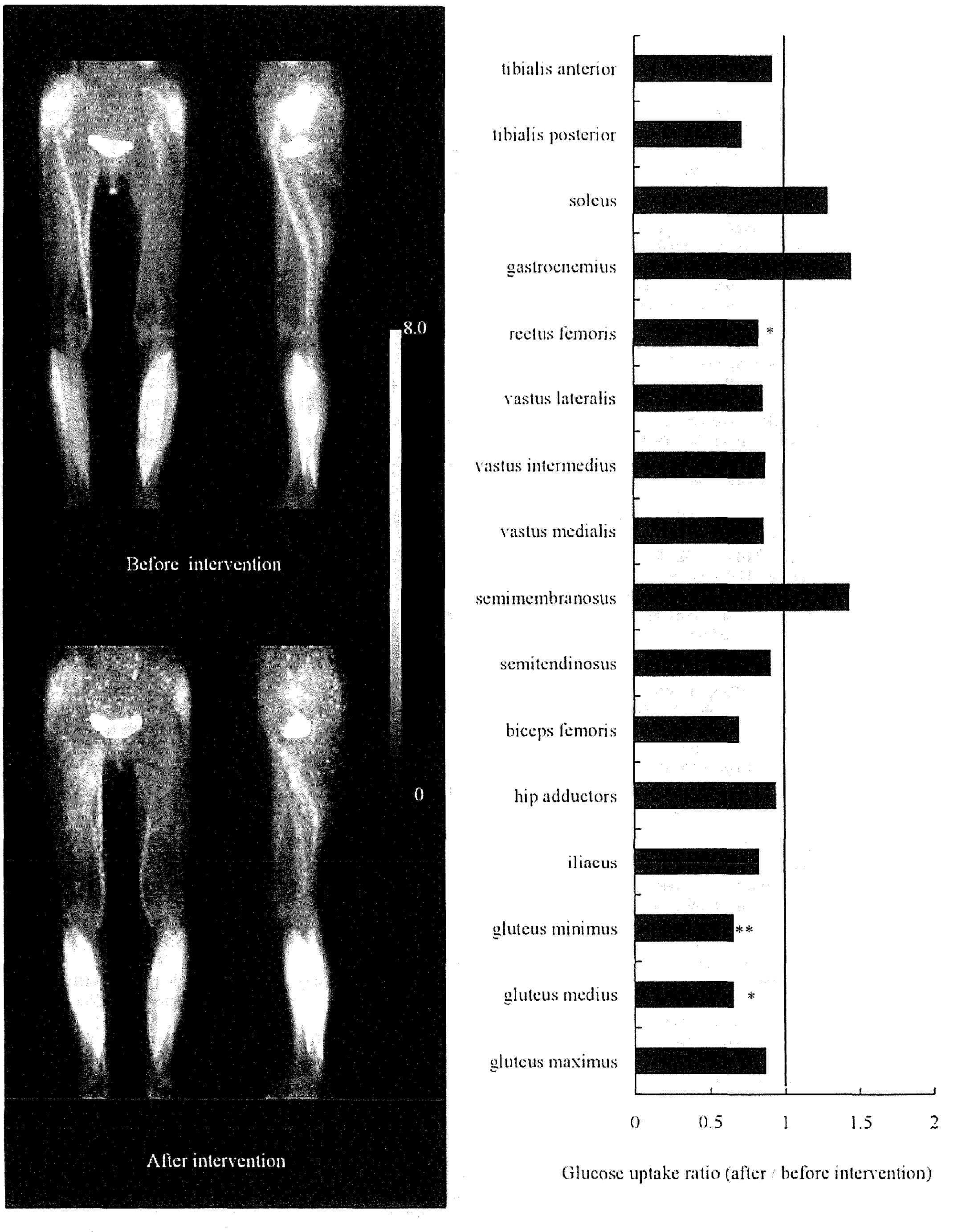

Fig. (3) FDG PET images of elderly women before and after the intervention.
$^*p<.05$, $^{**}p<.01$
The left and right panels show projection images of FDG PET and FDG uptake ratios between after and before intervention, respectively. FDG uptake by the gluteus minimus, gluteus medius, and rectus femoris was significantly lower after the intervention than before it.

CONFLICT OF INTEREST

The author has no financial or any other kind of personal conflicts with this paper.

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Effects of Exercise and Amino Acid Supplementation on Body Composition and Physical Function in Community-Dwelling Elderly Japanese Sarcopenic Women: A Randomized Controlled Trial

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OBJECTIVES: To evaluate the effectiveness of exercise and amino acid supplementation in enhancing muscle mass and strength in community-dwelling elderly sarcopenic women.

DESIGN: Randomized controlled trial.

SETTING: Urban community in Tokyo, Japan.

PARTICIPANTS: One hundred fifty-five women aged 75 and older were defined as sarcopenic and randomly assigned to one of four groups: exercise and amino acid supplementation (exercise + AAS; n = 38), exercise (n = 39), amino acid supplementation (AAS; n = 39), or health education (HE; n = 39).

INTERVENTION: The exercise group attended a 60-minute comprehensive training program twice a week, and the AAS group ingested 3 g of a leucine-rich essential amino acid mixture twice a day for 3 months.

MEASUREMENTS: Body composition was determined using bioelectrical impedance analysis. Data from interviews and functional fitness parameters such as muscle strength and walking ability were collected at baseline and after the 3-month intervention.

RESULTS: A significant group × time interaction was seen in leg muscle mass ($P = .007$), usual walking speed ($P = .007$), and knee extension strength ($P = .017$). The within-group analysis showed that walking speed significantly increased in all three intervention groups, leg muscle mass in the exercise + AAS and exercise groups, and knee extension strength only in the exercise + AAS group (9.3% increase, $P = .01$). The odds ratio for leg muscle mass and knee extension strength improvement was more than four times as great in the exercise + AAS group (odds ratio = 4.89, 95% confidence interval = 1.89–11.27) as in the HE group.

CONCLUSION: The data suggest that exercise and AAS together may be effective in enhancing not only muscle strength, but also combined variables of muscle mass and walking speed and of muscle mass and strength in sarcopenic women. **J Am Geriatr Soc 60:16–23, 2012.**

Key words: sarcopenic women; exercise; amino acid supplementation; muscle mass; muscle strength

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Sarcopenia, defined as age-related involuntary loss of skeletal muscle mass and strength,[1,2] has been associated with physical disability, functional decline, falls, impaired mobility, and mortality in elderly people.[3,4] Therefore, treating or reversing sarcopenia is important in the maintenance of health and life expectancy in the elderly population. Although many factors, such as chronic disease, physical inactivity, and decreased muscle protein synthesis, may contribute to loss of muscle mass,[5–7] it has been suggested that only skeletal muscle disuse and undernutrition are potentially preventable or reversible with targeted interventions.[8]

Many studies have shown a strong relationship between resistance exercise and strength improvement, through which the efficacy of resistance exercise for the prevention and treatment of sarcopenia has been confirmed.[9] The previous studies have also shown that ingestion of essential amino acids can induce muscle protein anabolism in elderly adults.[10,11] One study showed that the combination of resistance exercise and essential amino acid supplementation (AAS) augmented muscle protein

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synthesis, suggesting it as a strategy to reverse sarcopenia[12] but in a small sample size. There are few randomized controlled trials (RCTs) on the effects of exercise and AAS on body composition and functional capacity.

The purpose of this study was to investigate the effects of exercise and AAS on muscle mass, strength, and walking ability in sarcopenic women.

METHODS

Subjects

A letter outlining the comprehensive geriatric health examination survey, describing its objective and the way that the personal data would be used, was mailed to the women randomly selected from the Basic Resident Register of 5,932 people aged 75 and older residing in the Itabashi ward of metropolitan Tokyo inviting them to participate in the study. Two thousand eighteen people responded to the mailed letters of invitation to participate in the study, with 1,670 people agreeing and 348 people declining to participate. The baseline assessment was conducted at the Tokyo Metropolitan Institute of Gerontology (TMIG) from October 12 to November 3, 2008. One thousand three hundred eighty-three women aged 75 and older were screened; 287 who originally agreed to participation were absent. Written informed consent was obtained for baseline screening; six people did not sign the informed consent form and were not included in this study.

Three hundred four of 1,377 women (22.1%) were operationally defined as sarcopenic (Figure 1), with selection based on categorization into one or more of the following inclusion criteria groups: appendicular skeletal muscle mass/height^2 less than 6.42 kg/m^2 and knee extension strength less than 1.01 Nm/kg[13,14] (n = 68), appendicular skeletal muscle mass/height^2 less than 6.42 kg/m^2 and usual walking speed less than 1.22 m/s (n = 65),[14] body mass index (BMI) less than 22.0 kg/m^{2}[14] and knee

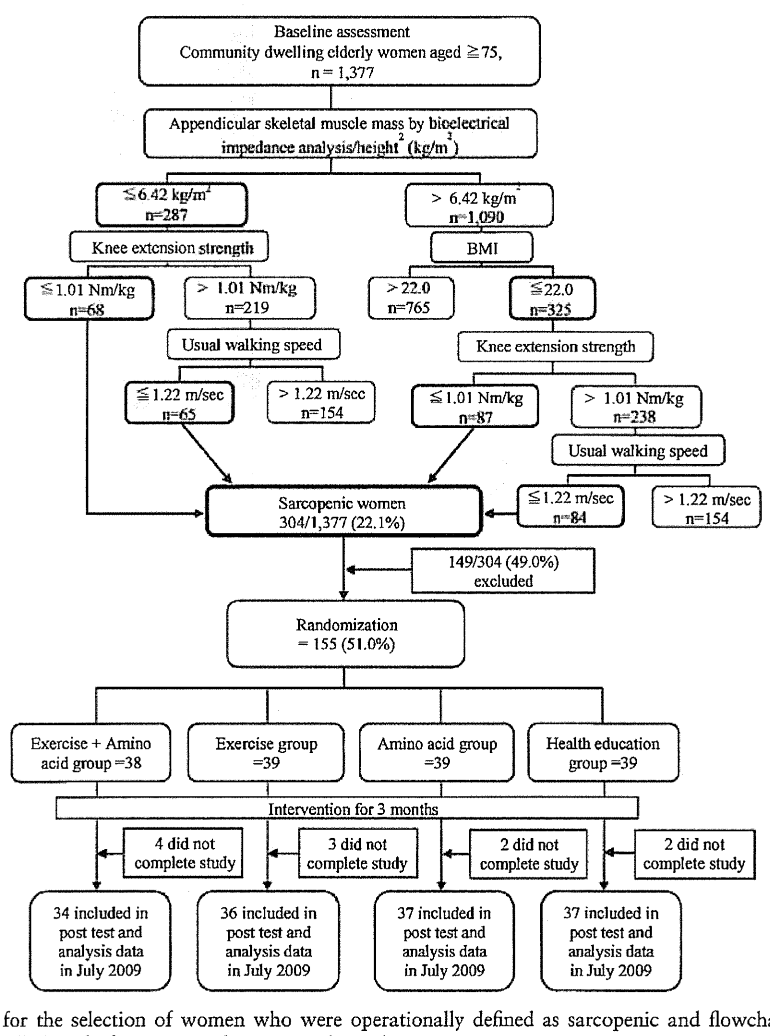

Figure 1. Algorithm for the selection of women who were operationally defined as sarcopenic and flowchart of participants in the randomized controlled trial of exercise and amino acid supplementation.

extension strength less than 1.01 Nm/kg (n = 87), and BMI less than 22.0 kg/m^2 and usual walking speed less than 1.22 m/s (n = 84). Exclusion criteria were severe knee or back pain; severely impaired mobility; impaired cognition (Mini-Mental State Examination (MMSE) score < 24);[16] missing baseline data; and unstable cardiac conditions such as ventricular dysrhythmias, pulmonary edema, or other musculoskeletal conditions. One hundred forty-nine (49.0%) of the potential sarcopenic participants were excluded because they were classified into one or more of the exclusion criteria or declined participation. The Clinical Research Ethics Committee of TMIG approved the study protocol. The intervention procedures were fully explained to all participants, and written informed consent was obtained (Figure 1).

Randomization

Randomization was performed after the baseline assessment; any variable that identified personal information was not included in the randomization process. Computer-generated random numbers were assigned to 155 participants who were then sorted and divided into four equal groups. The groups were randomly assigned to one of the four interventions groups: exercise + AAS (n = 38), exercise (n = 39), AAS (n = 39), or health education (HE; n = 39). All participants agreed to the group allocations that were mailed to them. There was no attempt to equalize the size of the groups based on their characteristics or to recruit subjects with specific characteristics. The co-investigators were blind to the randomization procedure and group allocations, separate physical therapy staff members who were also blind to the allocation of treatments collected data.

Outcome Measures

Outcome measures were evaluated according to data collected from interviews, body composition assessments using bioelectrical impedance analysis (BIA), and physical fitness tests at baseline and after the 3-month intervention.

Interview Survey

Face-to-face interviews were conducted to assess the individual's history of fractures and falls over the previous year, number of falls, cause of falls, urinary incontinence, exercise habits, smoking status, and MMSE score.

Body Composition Assessment

Measurements of height and weight were used to calculate BMI (kg/m^2). Body composition was measured using a segmental multifrequency BIA instrument that operated at frequencies of 5, 50, 250, and 550 kHz (Well-Scan 500, Elk Corp., Tokyo, Japan). Participants removed their socks, stood on two metallic electrodes on the floor scale barefoot, and held metallic grip electrodes placed in the palm of the hand with the fingers wrapped around the handrails. Using segmental body composition and muscle mass values of both legs, both arms, and the trunk, appendicular skeletal muscle mass and leg muscle mass values were obtained and used for analysis by summing the appropriate segmental muscle mass values.[13,17,18] Reliability of body composition measurements in all 155 participants in this study was not analyzed, although for the AAS group (n = 39), measurements were taken for a second time 1 week after baseline testing, and reliability was examined; the intraclass correlation coefficients (ICC) were: 0.98 for the right arm, 0.97 for the left arm, 0.97 for the right leg, 0.96 for the left leg, and 0.93 for the trunk.

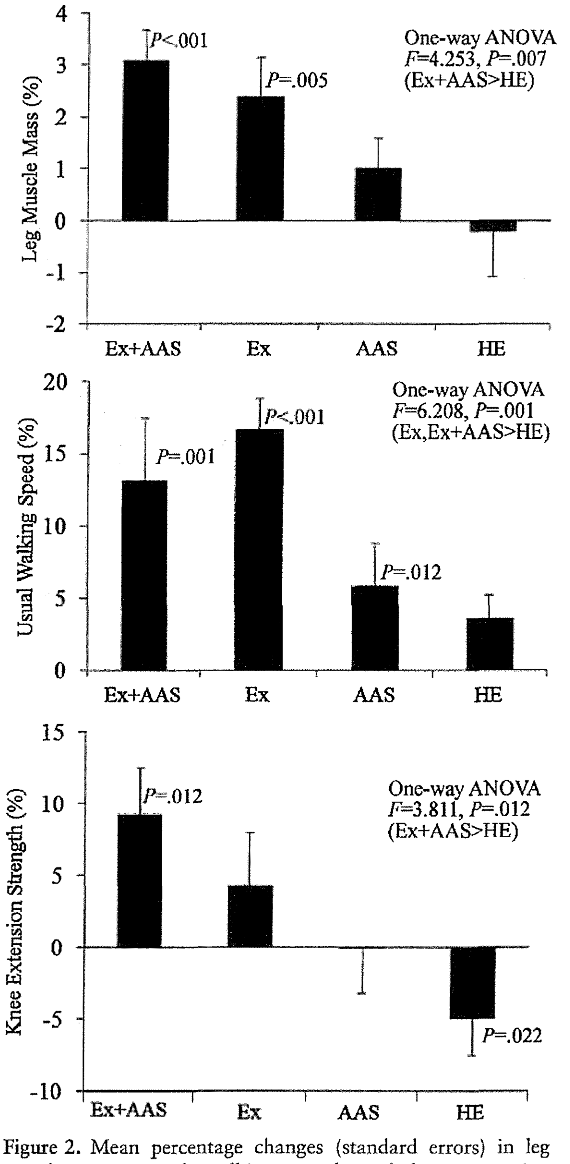

Figure 2. Mean percentage changes (standard errors) in leg muscle mass, usual walking speed, and knee extension strength after exercise (Ex), amino acid supplementation (AAS), both (Ex + AAS), or health education (HE). Bars indicate average changes from baseline to after the 3-month intervention. ANOVA = analysis of variance.