











Adolescent and Current Exercise Habits in Chronic Obstructive Pulmonary Disease: Associations with Body Composition, Physical Activity, and Pulmonary Function

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Purpose: Regular exercise significantly influences chronic obstructive pulmonary disease (COPD) outcomes. However, the associations of exercise habits during adolescence compared to current exercise habits on physical activity (PA), body composition, pulmonary function, and CT imaging parameters remain unclear. Therefore, the present study aimed to clarify the associations of adolescent and current exercise habits with current conditions.

Patients and Methods: This cross-sectional study enrolled 86 participants, including 72 with COPD and 14 with pre-COPD. Adolescent exercise habits were defined as regular exercise during ages 16 to 22 years, while current exercise habits were defined as regular exercise for at least 1 year. PA was assessed using a triaxial accelerometer, body composition was assessed using bioelectrical impedance analysis, and pulmonary function was assessed using spirometry and computed tomography.

Results: Adolescent exercise habits were not significantly associated with PA or body composition, although they were associated with an increased lung volume. Compared to adolescent exercise habits, current exercise habits were associated with an increased duration of active engagement, less sedentary behavior, and increased diffusing capacity. Moreover, current exercise habits were associated with increased fat-free mass index, bone mineral content, and phase angle, which is an indicator of muscle quality. The influence of current exercise habits on these musculoskeletal indicators remained significant even after adjusting for age, sex, disease severity, and adolescent exercise habits. In addition, the relationship between PA and musculoskeletal health was more pronounced in patients with moderate-to-severe COPD than in those with mild COPD.

Conclusion: Exercise during adolescence may promote increased lung volume. However, even after the onset of COPD, especially if the disease has progressed, regular exercise routines can help maintain PA, better body composition, and pulmonary function.

Keywords: triaxial accelerometer, sedentary behavior, bioelectrical impedance analysis, fat-free mass index, phase angle, COPD

Introduction

Chronic obstructive pulmonary disease (COPD) is a major public health concern, as it remains one of the leading causes of death worldwide.¹ Patients with COPD often experience reduced musculoskeletal mass due to chronic inflammation, malnutrition, and inactivity resulting from dyspnea.^{2,3} This musculoskeletal loss contributes to sarcopenia and osteoporosis, increasing fracture risk and further inactivity, which worsens prognosis.^{4,5} Exercise plays a vital role in maintaining healthy body composition.⁶ The Global Initiative for Chronic Obstructive Lung Disease (GOLD) 2025 report emphasizes the importance of pulmonary rehabilitation.⁷ However, its availability is limited due to high costs and

a shortage of therapists.⁸ Encouraging patients with COPD to establish their exercise habits may promote physical activity (PA) and help reduce healthcare costs.

Musculoskeletal mass reaches a peak in young adulthood and gradually declines with age.⁹ Higher levels of PA during youth are associated with increased lean mass, and maintaining PA in later life helps preserve it.⁶ However, to the best of our knowledge, no study has clarified the associations of adolescent versus current exercise habits on body composition in patients with COPD. Moreover, the association of adolescent exercise on current PA levels and pulmonary function in patients with COPD has not been thoroughly investigated.

We hypothesized that adolescent and current exercise habits would independently contribute to an improved clinical profile of COPD. In the present study, we aimed to clarify the associations of adolescent and current exercise habits with body composition, PA, and pulmonary function. Furthermore, we determined whether disease severity influences these effects.

Materials and Methods

Participants

Outpatients with COPD or pre-COPD at our university hospital between October 2021 and December 2023 were enrolled in this cross-sectional study, as part of exploratory research. Participants with a smoking history of more than 10 pack-years and no exacerbation of respiratory symptoms within 4 weeks prior to enrollment were included. The exclusion criteria included severe heart failure, progressive malignant diseases, or other chronic pulmonary diseases, except for stable asthma. COPD and pre-COPD were diagnosed according to the GOLD recommendations.⁷ In this study, Pre-COPD and GOLD 1 were defined as mild COPD (forced expiratory volume in 1 s [FEV₁] % predicted \geq 80%), and GOLD 2 to 4 were defined as moderate-to-severe COPD (FEV₁ % predicted $<$ 80%). This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. This study was approved by the Ethics Committee of Shiga University of Medical Science (registration number: R2021-026), and all participants provided written informed consent before participation.

Exercise Habit Questionnaire

Self-report questionnaires were used to ask the participants about their exercise habits at different stages of their lives ([Figure S1](#)). We defined exercise habit as engaging in any sport or exercise at least twice a week for a minimum of 30 min per session.¹⁰ Participants were categorized as “adolescent exercisers” if they had exercise habits between the ages of 16 and 22 years for at least 1 continuous year,¹¹ and as “current exercisers” if they had maintained exercise habits for at least 1 year.

PA Assessment

PA was measured using a triaxial accelerometer (Active Style Pro HJA-750C; Omron Healthcare, Kyoto, Japan). The participants wore the device during the daytime, except while bathing, for 14 days. Rainy days were excluded, and the data were validated as previously described.¹² The mean durations of PA based on metabolic equivalents (METs) and step counts were analyzed. The intensity of PA was defined as moderate to vigorous PA (moderate to vigorous physical activity [MVPA] \geq 3.0 METs), light PA (1.6 to 2.9 METs), and sedentary behavior (1.0 to 1.5 METs), based on a previous report.¹³

Body Composition Analysis

Body composition was assessed using direct segmental multifrequency bioelectrical impedance analysis (BIA) (InBody S10; InBody Co., Ltd., Seoul, South Korea).⁶ Multifrequency measurements were performed for each body segment in the supine position. Fat-free mass index (FFMI) and fat mass index (FMI) were calculated by dividing the respective mass values by height squared. Phase angle (PhA), a raw BIA variable, reflects the relationship between reactance and resistance in the body as a conductor, and a smaller value indicates a worse cellular condition.¹⁴ The PhA at 50 kHz provides information about muscle quality.^{14,15}

Handgrip Strength Test

Handgrip strength was measured twice per hand, and the maximum value was analyzed.

6-minute Walk Test

A 6-minute walk test was performed according to the guidelines.¹⁶

Pulmonary Function Tests

Pulmonary function tests were performed after the inhalation of 20 µg procaterol using a spirometer (FUDAC77; Fukuda Denshi, Tokyo, Japan), according to the ATS/ERS guidelines.¹⁷ Carbon monoxide diffusing capacity was measured using the single-breath washout technique. Predicted spirometry values were calculated according to the Japanese Respiratory Society guidelines.¹⁸

Computed Tomography Imaging

Chest computed tomography (CT) was performed in the supine position using a 320-detector row CT scanner (Aquilion ONE; Canon Medical Systems Corporation, Tochigi, Japan) with full inspiration. The 20 µg procaterol inhalation was given 1 hour before CT scan. Emphysematous lesions were assessed as the percentage of low attenuation volume (LAV%), which is defined as the percentage of lung volume exhibiting CT attenuation values below −950 Hounsfield units. Small airway lesions were assessed by plotting the square root of the wall area (\sqrt{Aaw}) of each visible bronchial segment against its internal perimeter, and estimating the \sqrt{Aaw} for a hypothetical airway with an internal perimeter of 10 mm using linear regression (\sqrt{Aaw} at Pi10). All parameters were quantified using the Apollo software version 1.2 (VIDA, Coralville, IA, USA), based on previous reports.^{19,20}

Statistical Analysis

Statistical analyses were performed using JMP Pro 17 software (SAS Institute, Cary, NC, USA). Differences between exercisers and non-exercisers were evaluated using the Wilcoxon rank-sum and Fisher's exact tests. The correlations between PA and body composition were assessed using Spearman's rank correlation coefficients. Statistical significance was set at $p < 0.05$.

Table 1 Patient Characteristics

	Total (n = 86)
Age (years, median [IQR])	76.0 (70.0–80.0)
Male (n, %)	81 (94.2)
BMI (kg/m ² , median [IQR])	24.2 (21.9–25.8)
Current smoker (n, %)	16 (18.6)
Pack-years (median [IQR])	50.0 (38.8–69.8)
mMRC score (median [IQR])	1.0 (0.0–1.0)
CAT score (median [IQR])	8.0 (3.0–14.5)
COPD (n, %)	72 (83.7)
GOLD stage (n)	
Pre-COPD/1/2/3/4	14/36/25/9/2
Cardiovascular disease (n, %)	14 (16.3)
Osteoporosis (n, %)	3 (3.5)
Bronchodilator use (n, %)	60 (69.8)
Hand grip tests (kg, median [IQR])	33.6 (28.7–38.6)
6MWD (m, median [IQR]) ^a	400 (362–433)
Adolescent exerciser (n, %)	46 (53.5)
Current exerciser (n, %)	61 (70.9)

Notes: ^an = 60.

Abbreviations: IQR, interquartile range; BMI, body mass index; mMRC, modified Medical Research Council dyspnea scale; CAT, COPD Assessment Test; GOLD, Global Initiative for Chronic Obstructive Lung Disease; 6MWD, 6-minute walk test distance.

Results

A total of 86 participants (81 men and 5 women) were enrolled in this study. Seventy-two patients were diagnosed with COPD, and 36 patients were diagnosed with moderate-to-severe COPD (Table 1). As presented in Figure S2, there was no relationship between the presence or absence of adolescent exercise habits and current exercise habits. Adolescence and current exercise habits were not related to exercise habits in the 30s to 40s.

Association Between Adolescent Exercise Habits and Current Conditions

The demographic and clinical characteristics of the participants were not significantly different between adolescent exercisers and non-exercisers (Table S1). Adolescent exercise habits did not influence step count, PA duration at any intensity, (Figure 1A–D), or body composition parameters (Figure 1E–H). When pulmonary function and CT imaging were determined, only vital capacity was significantly higher in adolescent exercisers than in non-exercisers ($p = 0.038$; Table 2).

Association Between Current Exercise Habits and Current Conditions

Table S2 presents the demographic and clinical characteristics of current exercisers and non-exercisers. Current non-exercisers were more likely to be current smokers or female sex. They also showed a non-significant trend toward lower grip strength. Current exercisers were more physically active ($p < 0.001$; Figure 2A, and $p < 0.001$; Figure 2B) throughout the day. The duration of light PA tended to be longer in current exercisers than in non-exercisers, but this difference was not significant ($p = 0.059$; Figure 2C). Current exercisers spent less time engaging in sedentary behaviors ($p = 0.021$; Figure 2D). Body composition measures, including FFMI ($p = 0.002$; Figure 2E), bone mineral content (BMC, $p = 0.009$; Figure 2F), and PhA ($p = 0.017$; Figure 2G), were significantly higher in current exercisers than in non-exercisers, whereas the FMI ($p = 0.52$; Figure 2H) and body mass index (BMI; $p = 0.42$; Table S2) showed no significant differences. Multiple linear regression analysis, adjusted for age, sex, FEV₁ % predicted, and both adolescent and current exercise habits, revealed that current exercise habits were independent factors affecting FFMI, BMC, and PhA (Table 3). The results remained consistent when an interaction term between adolescents and their current exercise habits was incorporated into the multivariate analysis (data not shown). Although CT imaging parameters were not related to current exercise habits, diffusing capacity was higher in current exercisers than in non-exercisers ($p = 0.006$; Table 4).

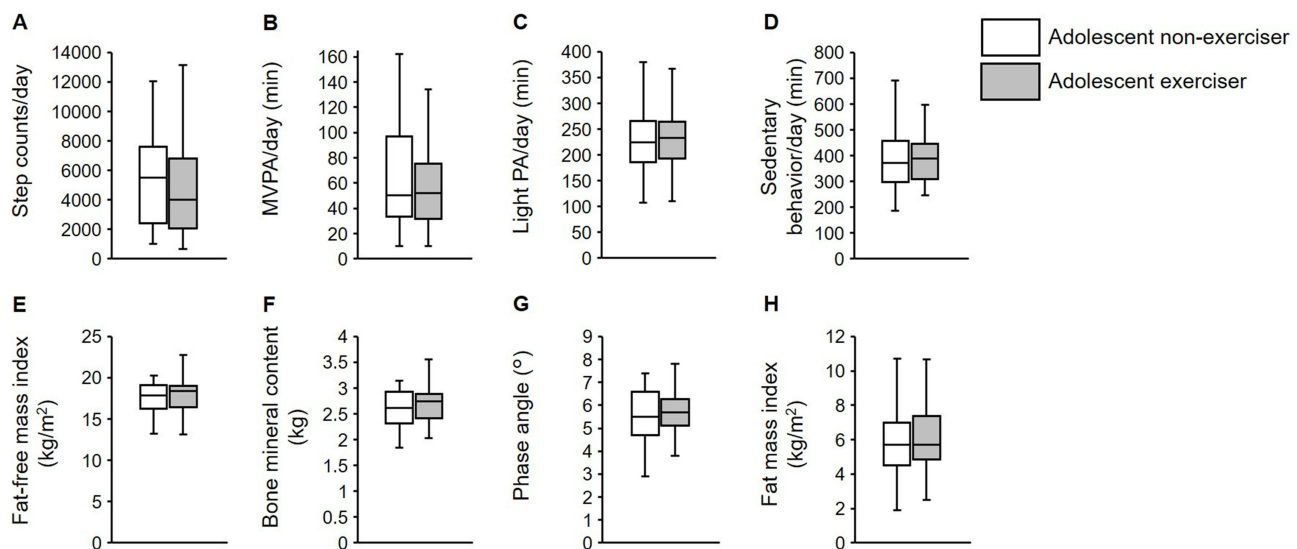


Figure 1 Associations of adolescent exercise habits with physical activity and body composition parameters. **(A)** Comparison of step counts per day. **(B)** Comparison of MVPA per day. **(C)** Comparison of light PA per day. **(D)** Comparison of sedentary behavior per day. **(E)** Comparison of fat-free mass index. **(F)** Comparison of bone mineral content. **(G)** Comparison of phase angle at 50 kHz. **(H)** Comparison of fat mass index.

Abbreviations: MVPA, moderate to vigorous physical activity; PA, physical activity.

Table 2 Associations of Adolescent Exercise Habits with Pulmonary Functions and CT Imaging Biomarkers

	Adolescent		
	Non-Exerciser (n = 40)	Exerciser (n = 46)	P-value
FEV ₁ % predicted (%)	82.9 (71.0–92.9)	82.6 (59.2–95.2)	0.88
VC % predicted (%)	104.5 (94.0–115.2)	112.3 (101.0–125.5)*	0.038
RV/TLC (%)	37.8 (34.0–42.9)	37.3 (33.1–40.7)	0.33
DL _{CO} /V _A (mL/min/mmHg/L)	3.4 (2.5–3.8)	3.1 (2.4–3.8)	0.38
LAV% (%) ^a	5.2 (2.3–14.9)	8.0 (4.1–13.7)	0.14
√Aaw at Pi10 (mm) ^a	3.76 (3.71–3.81)	3.79 (3.74–3.85)	0.091

Notes: Data are presented as medians (interquartile range). * is significant at the P < 0.05 level. ^an = 40 (non-exerciser) and 43 (exerciser).

Abbreviations: FEV₁, forced expiratory volume in 1 s; VC, vital capacity; RV, residual volume; TLC, total lung capacity; DL_{CO}/V_A, carbon monoxide diffusing capacity divided by the alveolar volume; LAV, low attenuation volume; √Aaw at Pi10, square root of the wall area of a hypothetical airway with an internal perimeter of 10 mm.

Associations Between MVPA per Day and Body Composition Parameters by COPD Severity

As presented in Table 5 and Figure 3, MVPA per day was positively correlated with the FFMI and PhA, especially in moderate-to-severe COPD ($\rho = 0.51$, $p = 0.003$; $\rho = 0.45$, $p = 0.011$, respectively). In contrast, in mild COPD, MVPA per day was associated with the PhA and FMI ($\rho = 0.32$, $p = 0.024$; $\rho = -0.29$, $p = 0.042$, respectively).

Discussion

In patients with COPD, adolescent exercise habits showed no significant association with daily PA levels or body composition, although they were associated with increased lung volume. In contrast, current exercise habits were associated with prolonged engagement in higher PA, with a reduction in sedentary behavior, improved body composition, and enhanced diffusing capacity. In addition, the correlation between PA and musculoskeletal parameters varied with COPD severity and was more pronounced in patients with moderate-to-severe COPD than in those with mild COPD.

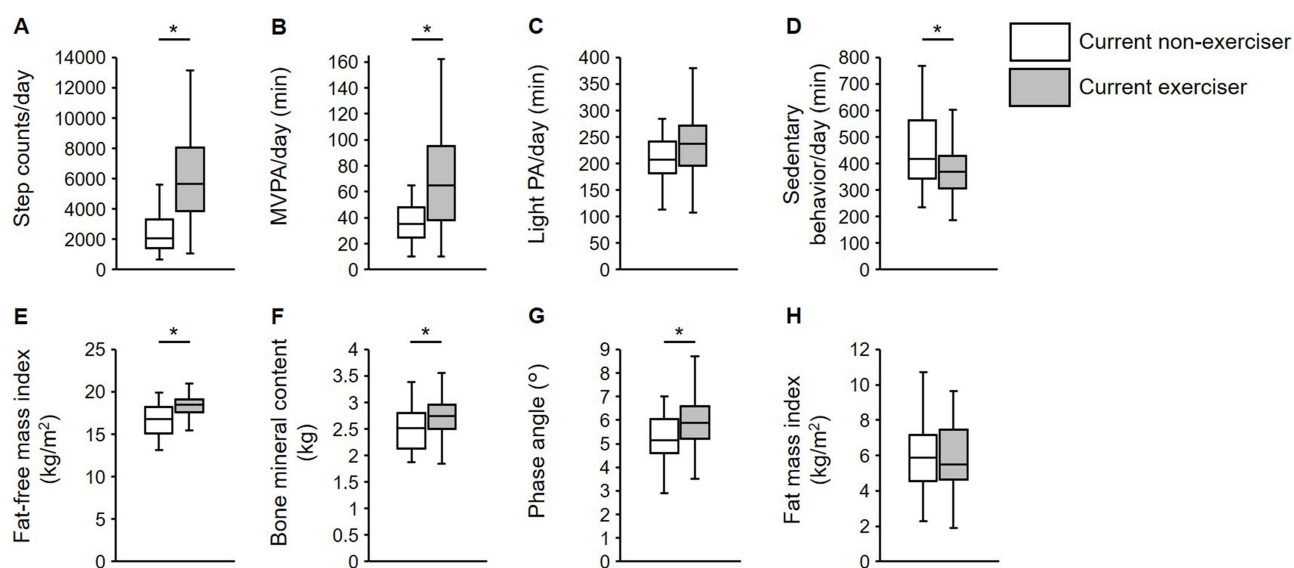


Figure 2 Associations of current exercise habits with physical activity and body composition parameters. *is significant at the P < 0.05 level. **(A)** Comparison of step counts per day. **(B)** Comparison of MVPA per day. **(C)** Comparison of light PA per day. **(D)** Comparison of sedentary behavior per day. **(E)** Comparison of fat-free mass index. **(F)** Comparison of bone mineral content. **(G)** Comparison of phase angle at 50 kHz. **(H)** Comparison of fat mass index.

Abbreviations: MVPA, moderate to vigorous physical activity; PA, physical activity.

Table 3 Factors Associated with Body Composition Parameters Based on the Multiple Linear Regression Test

Variable	FFMI (kg/m ²)			BMC (kg)			PhA (°)		
	β	95% CI	P-value	β	95% CI	P-value	β	95% CI	P-value
Age (10 years)	-0.88*	[-1.38, -0.38]	< 0.001	-0.22*	[-0.33, -0.11]	< 0.001	-0.77*	[-1.06, -0.48]	< 0.001
Sex (Male = 1)	1.28*	[1.00, 4.10]	0.001	0.32*	[0.30, 0.98]	< 0.001	0.20	[-0.50, 1.30]	0.37
FEV ₁ % predicted (10%)	0.10	[-0.07, 0.26]	0.26	0.01	[-0.02, 0.05]	0.48	0.01	[-0.08, 0.11]	0.76
Adolescent exercise habits (yes = 1)	0.17	[-0.54, 0.88]	0.63	0.05	[-0.10, 0.21]	0.49	0.12	[-0.29, 0.54]	0.55
Current exercise habits (yes = 1)	1.22*	[0.42, 2.03]	0.003	0.19*	[0.01, 0.36]	0.036	0.62*	[0.15, 1.08]	0.010

Notes: * is significant at the P < 0.05 level. Multiple regressions including the interaction (adolescent exercise habits*current exercise habits) were performed, but the P-value of the interaction term was above the significance level and the statistically significant points were the same as in the table. Therefore, the results of multiple regression without the interaction term were reported.

Abbreviations: FFMI, fat-free mass index; BMC, bone mineral content; PhA, phase angle at 50 kHz; CI, confidence intervals; FEV₁, forced expiratory volume in 1 s.

Table 4 Associations of Current Exercise Habits with Pulmonary Functions and CT Imaging Biomarkers

	Current		
	Non-Exerciser (n = 25)	Exerciser (n = 61)	P-value
FEV ₁ % predicted (%)	83.0 (58.1–90.8)	82.7 (68.8–95.5)	0.49
VC % predicted (%)	108.7 (101.1–115.9)	107.4 (96.4–117.7)	0.86
RV/TLC (%)	37.3 (32.2–42.3)	37.4 (34.1–41.8)	0.89
DL _{CO} /V _A (mL/min/mmHg/L)	2.5 (2.0–3.5)	3.4 (2.6–3.9)*	0.006
LAV% (%) ^a	9.5 (3.4–22.7)	6.4 (2.7–13.2)	0.12
√Aaw at Pi10 (mm) ^a	3.79 (3.74–3.82)	3.76 (3.70–3.84)	0.65

Notes: Data are presented as medians (interquartile range). * is significant at the P < 0.05 level. ^an = 25 (non-exerciser) and 58 (exerciser).

Abbreviations: FEV₁, forced expiratory volume in 1 s; VC, vital capacity; RV, residual volume; TLC, total lung capacity; DL_{CO}/V_A, carbon monoxide diffusing capacity divided by the alveolar volume; LAV, low attenuation volume; √Aaw at Pi10, square root of the wall area of a hypothetical airway with an internal perimeter of 10 mm.

Table 5 Associations Between MVPA per Day and Body Composition Parameters by COPD Severity

MVPA Per Day	FFMI (kg/m ²)		BMC (kg)		PhA (°)		FMI (kg/m ²)	
	Rho	P-value	Rho	P-value	Rho	P-value	Rho	P-value
In all participants	0.26*	0.021	0.17	0.14	0.38*	<0.001	-0.24	0.029
In mild COPD	0.08	0.58	0.04	0.78	0.32*	0.024	-0.29*	0.042
In moderate-to-severe COPD	0.51*	0.003	0.33	0.070	0.45*	0.011	-0.18	0.33

Notes: * is significant at the P < 0.05 level.

Abbreviations: MVPA, moderate to vigorous physical activity; FFMI, fat-free mass index; BMC, bone mineral contents; PhA, phase angle at 50 kHz; FMI, fat mass index.

Previous studies have suggested that in healthy older adults, youth sports participation is associated with elevated PA levels and improved body composition in later life.^{21,22} Contrary to our hypothesis, adolescent exercisers neither showed a tendency to maintain a high level of PA nor a better body composition in later life. Prolonged chronic inflammation, disease-related inactivity, particularly due to breathlessness, and COPD comorbidities may negate any long-term benefits of adolescent exercise.^{2,5} Although adolescent exercise habits did not significantly affect COPD features, a notable finding was a higher lung volume in adolescent exercisers than in non-exercisers. Our results align with those of earlier studies in healthy adults;^{23,24} however, to the best of our knowledge, our study is the first to describe this association in patients with COPD. Although the mechanisms underlying lung development through exercise are not fully understood, regular exercise during adolescence may be associated with lung development.^{23,24} As impaired lung development

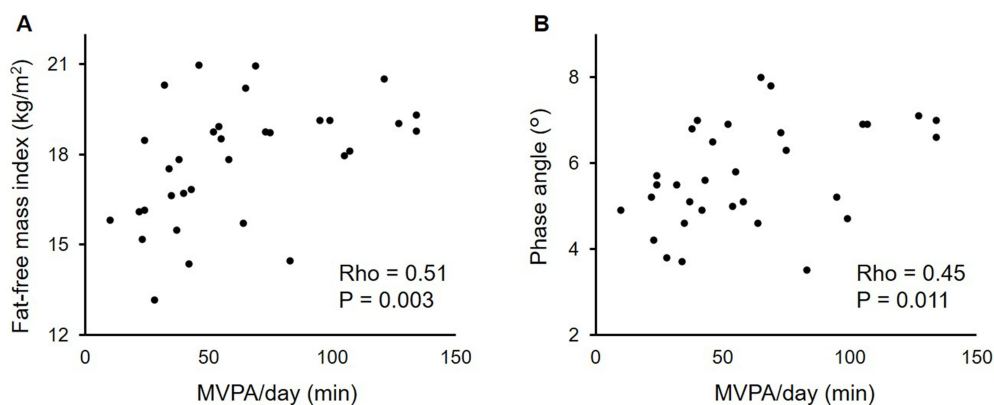


Figure 3 Correlations between MVPA per day and muscle quantity or quality indicators in moderate-to-severe COPD. **(A)** Correlation between MVPA per day and fat-free mass index. **(B)** Correlation between MVPA per day and phase angle at 50 kHz.

Abbreviation: MVPA, moderate to vigorous physical activity.

reportedly contributes to the future onset of obstructive lung diseases, early life exercise may play a beneficial role in preventing the development or progression of COPD.²⁵

In the present study, current exercisers were physically active regularly and did not exhibit sedentary behaviors such as prolonged periods of television viewing. Increased PA is associated with improved body composition in COPD.^{26,27} Consistently, our study demonstrated that current exercisers had significantly higher musculoskeletal measures than non-exercisers. Furthermore, these associations persisted even after adjusting for confounders, including adolescent exercise habits. It is possible that patients with well-controlled COPD are more likely to maintain exercise routines. However, regular exercise, even after the onset of COPD, may be more important than exercise during adolescence for achieving optimal body composition, leading to a good prognosis and indirectly contributing to reduced healthcare costs.⁴ Moreover, a low level of PA is associated with muscle wasting and reduced exercise performance.²⁷ Although the difference in grip strength was not statistically significant—possibly due to the relatively small sample size—grip strength, a reported prognostic factor, tended to be higher in current exercisers.^{28,29}

Diffusing capacity was significantly higher in current exercisers, which is consistent with the findings of a previous observational study.³⁰ However, there were no statistically significant differences in CT imaging factors. Individuals with a higher diffusing capacity may engage in higher levels of PA. However, regular exercise may promote pulmonary circulation at the capillary level and prevent a decrease in diffusing capacity,³⁰ regardless of morphological changes. Further studies are required to investigate these causal relationships.

In addition, we observed correlations between the duration of MVPA and musculoskeletal parameters in patients with moderate-to-severe COPD, consistent with a previous study.³¹ Patients with more severe COPD reportedly have lower musculoskeletal mass and experience faster muscle loss than those with mild disease.^{2,3,20} Notably, exercise-induced changes in the muscle are not impaired in patients with severe COPD, and exercise may have an even greater impact on body composition in this population.³² Our finding further suggests that maintaining daily PA levels is crucial for preventing musculoskeletal mass loss, particularly in patients with more severe COPD.

This study had some limitations. This was a single-center study conducted in Japan with a relatively small sample size. As a cross-sectional study, it cannot establish causal relationships, and recall bias may have occurred. Moreover, nutritional supplementation, which may be related to body composition, was not evaluated. However, no participant reported anorexia at the time of examination. Further prospective studies are needed to confirm our findings and explore the mechanisms underlying these associations.

Conclusion

Exercise during adolescence may be associated with increased lung volume. However, even after the onset of COPD, regular exercise routines can help maintain PA, improve body composition, and diffusing capacity, particularly if the

disease has progressed. The results of this study effectively underscore the importance of exercise habits in patients with COPD.

Acknowledgments

The authors would like to thank Yasutaka Horii, Yukie Miyatake, and Yoko Naito for their assistance throughout this study.

Disclosure

The authors report no conflicts of interest in this work.

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