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Alveolar volume; diffusing capacity of the lung for carbon monoxide (DLCO); pulmonary diffusing capacity; running; spirometry; tennis.

Pulmonary Diffusing Capacity and Spirometry Across Exercise Modalities: A Cross-Sectional Comparison of Young Male Groups

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ABSTRACT: Background: Spirometry assesses ventilation but does not measure alveolar–capillary gas transfer. Comparative evidence across continuous aerobic and intermittent aerobic–anaerobic exercise remains limited. We compared spirometry, DLCO, alveolar volume (VA), and transfer coefficient (KCO) among young male runners, tennis players, and controls.

Methods: This cross-sectional study included 75 men in running, tennis, and control groups. Spirometry and single-breath DLCO testing followed ATS/ERS standards. Groups were compared using one-way ANOVA or Kruskal–Wallis tests. Percent-predicted DLCO and VA were evaluated using covariate-adjusted ANCOVA, with Quade nonparametric ANCOVA as a sensitivity analysis.

Results: FEV1% was higher in runners and tennis players than controls ($p=0.014$ and 0.004). Runners had higher DLCO and DLCO% than controls (both $p<0.001$) and higher VA than controls and tennis players ($p=0.008$ and 0.030); KCO was similar. Adjusted analyses confirmed higher DLCO% ($B=0.164$; 95% CI, 0.074–0.254; $p<0.001$) and VA% ($p=0.007$) in runners versus controls. Sensitivity analysis reinforced the DLCO% findings but did not show the same consistency for VA%.

Conclusion: Running and tennis were associated with pulmonary function profiles distinct from controls. Comparable DLCO and KCO between exercise groups did not indicate superiority of either modality.

1. INTRODUCTION

Pulmonary function assessment encompasses two complementary physiological domains: mechanical ventilation and alveolar-capillary gas transfer. Spirometry quantifies expiratory volumes and airflow through forced vital capacity (FVC), forced expiratory volume in one second (FEV1), and the FEV1/FVC ratio, but does not directly assess gas transfer. Gas transfer is evaluated using the diffusing capacity of the lung for carbon monoxide (DLCO), mathematically expressed as the product of measured alveolar volume (VA) and the transfer coefficient of the lung for carbon monoxide (KCO) [1]. DLCO should therefore be interpreted alongside VA and KCO to distinguish the lung volume participating in gas exchange from gas transfer at that volume. Integrating diffusing capacity with spirometry provides a more complete assessment of ventilation and gas exchange.

Exercise increases metabolic demand, requiring parallel increases in ventilation and cardiac output [2]. Although cardiovascular and skeletal muscle adaptations to training are well established, evidence of structural pulmonary adaptation remains limited and its mechanisms unresolved.[3] In 16 young runners, Dridi *et al.* found that eight weeks of high-intensity endurance training

increased TLCO, alveolar-capillary membrane diffusing capacity, and pulmonary capillary blood volume; comparable changes were not observed with moderate-intensity training [4]. These findings suggest an intensity-dependent diffusing-capacity response, although the evidence derives from a small endurance-sport cohort.

The association between sport type and spirometry is also inconsistent. Rajaure *et al.* found no significant differences in FVC or FEV1 between aerobic and anaerobic athletes, indicating that energy-system classification alone may not explain variation in pulmonary function [5]. Endurance running is rhythmic, sustained, and predominantly aerobic, whereas tennis is intermittent, spans a broad intensity range, and draws on both aerobic and anaerobic metabolism [3,6]. These contrasting demands provide a physiological basis for comparing their pulmonary function profiles.

Previous studies have generally examined spirometry in aerobic and anaerobic athletes or assessed pulmonary diffusing capacity in endurance runners separately [4,5]. Evidence directly comparing ventilatory function and pulmonary diffusion across continuous aerobic exercise, intermittent mixed aerobic-anaerobic exercise, and no structured training remains limited. This study therefore compared pulmonary diffusing capacity (DLCO, VA, and KCO) and spirometric indices (FEV1, FVC, FEV1/FVC, and vital capacity [VC]) among young adult men who regularly participated in running or tennis and controls without structured exercise training.

2. MATERIALS AND METHODS

2.1 Study Design

This comparative cross-sectional study was conducted at Wahidin Sudirohusodo Hospital, Makassar, Indonesia, from January to May 2026. Seventy-five men aged >18 years were enrolled in equal-sized running, tennis, and control groups. Runners were recruited from the State Police School, tennis players from the Hasanuddin University Tennis Club, and controls from Wahidin Sudirohusodo Hospital. Consecutive sampling was used for the running and control groups, whereas all eligible tennis players were recruited by total sampling.

2.2 Ethical Clearance

The study was approved by the Health Research Ethics Committee of the Faculty of Medicine, Hasanuddin University. All participants provided written informed consent, and the study was conducted in accordance with the Declaration of Helsinki.

2.3 Sample Recruitment and Collection

minimum sample size for each group was 25 (minimal total sample: 75). The sampling method was selected based on group characteristic. Consecutive sampling was applied for aerobic and control group while total sampling was used for aerobic-anaerobic group since the population size was limited. The inclusion criteria were adult men (> 18 years old), hemoglobin ≥10 g/dL, no medication known to affect pulmonary function, and completion of acceptable and reproducible spirometry and DLCO measurements, having running exercise > 3 times/week for the last 6 months (aerobic group), having tennis > 3 times / week for the last 6 months (aerobic-anaerobic group), and not having regular exercise in the last 6 months (control group). The exclusion criteria were chronic pulmonary disease, clinically significant cardiovascular disease, severe hematologic disorders, and acute infection or illness at assessment.

Demographic characteristics, medical history, smoking, and training patterns were recorded using a questionnaire. Smoking exposure was quantified using the Brinkman Index. Height and weight were measured to calculate body mass index (BMI), and hemoglobin was obtained from a complete blood count. The exercise intensity, frequency, and duration were assessed using physical activity questionnaire and presented in Metabolic Equivalent of Task (METs), and classified based on American College of Sport Medicine (ACSM) standard. Spirometry measured FEV1, FVC, FEV1/FVC, and VC. Pulmonary diffusing capacity was assessed using the single-breath method in accordance with ATS/ERS standards following these steps: (1) Nose clip and mouthpiece were used, (2) the participants were asked to do tidal breathing, and then (3) followed by slow exhale to achieve residual volume, (4) inhaled rapidly to total lung capacity, (5) held their breath for 10 ± 2 seconds, and (6) exhaled in a controlled manner. The DLCO, VA, and KCO were recorded. All data were documented and validated to ensure they met acceptability and repeatability criteria based on ATS/ERS standard prior analysis. The data were analyzed if they met acceptability and reproducibility criteria were analyzed.

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2.4. Statistical Analysis

Analyses were performed using SPSS version 30.0.0. Continuous data are presented as mean ± standard deviation or median and interquartile range; categorical data are reported as counts and percentages. Normality was assessed using the Shapiro-Wilk test. The three groups were compared using one-way ANOVA or the Kruskal-Wallis test, followed by Tukey HSD or Mann-Whitney post hoc testing with Bonferroni correction. The associations between potential confounders (body weight, BMI, hemoglobin, and Brinkmann Index) and pulmonary function were assessed using Pearson or Spearman correlation to ensure the to improve the validity because those factors may affect baseline lung capacity. Between-group differences in percent-predicted DLCO and VA were further evaluated using ANCOVA adjusted for age, BMI, Brinkman Index, and hemoglobin. Because Levene's test indicated heteroscedasticity, Quade nonparametric ANCOVA was performed as a sensitivity analysis to assess the result consistency. A two-sided $p < 0.05$ was considered statistically significant.

3. RESULTS

3.1 Demographic and Baseline Data

The study included 75 young adult men, with 25 participants in each group. The overall mean age was 20.68 ± 1.71 years. Groups did not differ significantly in age ($p = 0.242$), height ($p = 0.198$), hemoglobin ($p = 0.810$), smoking status ($p = 0.095$), or Brinkman Index ($p = 0.092$). Body weight and BMI differed significantly ($p = 0.004$ and $p = 0.002$, respectively). Controls had the highest weight and BMI (72.52 ± 12.57 kg and 25.14 ± 3.88 kg/m²), compared with runners (63.88 ± 7.00 kg and 22.20 ± 2.00 kg/m²) and tennis players (64.40 ± 9.43 kg and 22.90 ± 2.66 kg/m²) (Table 1).

Running and tennis were classified as vigorous-intensity sports. Runners trained 4.96 ± 0.93 times weekly for 60 minutes per session, corresponding to approximately 298 minutes per week. Tennis players trained 3.44 ± 0.51 times weekly for 120 minutes per session, or approximately 413 minutes per week. Most participants were nonsmokers. Smoking prevalence was 20% among runners and 4% in both the tennis and control groups. The overall mean Brinkman Index was 1.27 ± 4.29, and all smokers had low cumulative exposure (Table 1).

Table 1. Demographic and Baseline Exercise Data

Variables	Control (n=25)	Running (n=25)	Tennis (n=25)	Total (n=75)	p-value
Exercise intensity	Mild	Severe	Severe	—	—
Age (years), Mean±SD	21.12±2.05	20.52±1.85	20.40±1.04	20.68±1.71	0.242
Body height (cm), Mean±SD	169.68±4.85	169.56±5.06	167.44±4.01	168.89±4.71	0.198
Body weight (kg), Mean±SD	72.52±12.57	63.88±7.00	64.40±9.43	66.93±10.57	0.004
BMI (kg/m²), Mean±SD	25.14±3.88	22.20±2.00	22.90±2.66	23.41±3.17	0.002
Hb (g/dL), Mean±SD	14.13±1.40	14.30±0.93	14.19±1.27	14.21±1.19	0.810
Frequency (times/week), Mean±SD	0.00±0.00	4.96±0.93	3.44±0.51	—	<0.001
Frekuensi, Median [IQR]	0 [0–0]	5 [4–6]	3 [3–4]	—	<0.001
Duration (minute/session), constant	0	60	120	—	<0.001

Exeecise volume/week (minute)	0	~298	~413	—	—
Not smoking, n (%)	24 (96.0%)	20 (80.0%)	24 (96.0%)	68 (90.7%)	0.095
Smoking, n (%)	1 (4.0%)	5 (20.0%)	1 (4.0%)	7 (9.3%)	—
Brinkman index, Mean±SD	0.80±4.00	2.36±5.36	0.64±3.20	1.27±4.29	0.092
BMI= Body mass index; Hb= Hemoglobin; IQR= Interquartile range; p= Probability values; ANOVA or Kruskal-Wallis Test.					

3.2 The Comparison of Lung Function

Eight of 19 pulmonary function measures differed significantly among groups: percent-predicted FVC, absolute FEV1, percent-predicted FEV1, FEV1/FVC, absolute DLCO, percent-predicted DLCO, absolute VA, and percent-predicted VA. Reference-predicted values for VC, FVC, FEV1, DLCO, KCO, and VA did not differ among groups. Percent-predicted FVC was 85 ± 6% in controls, 91 ± 16% in runners, and 94 ± 7% in tennis players (p = 0.013). Post hoc analysis showed a higher value in tennis players than controls (p = 0.011); other pairwise comparisons were not significant (Table 2).

Absolute FEV1 also differed among groups (p = 0.022): 3.52 ± 0.33 L in controls, 3.90 ± 0.74 L in runners, and 3.86 ± 0.37 L in tennis players (Table 2). The runner-control difference was significant (p = 0.031) (Table 3). A more consistent pattern emerged for percent-predicted FEV1, which was 84 ± 6%, 93 ± 17%, and 95 ± 6%, respectively (p = 0.002) (Table 2). Values were higher in runners (p = 0.014) and tennis players (p = 0.004) than controls, with no runner-tennis difference (p = 0.898) (Table 3). FEV1/FVC also differed among groups (p = 0.035), primarily between runners and controls (87 ± 7% vs 84 ± 4%; p = 0.031) (Table 2). Absolute VC, percent-predicted VC, and absolute FVC did not differ significantly (Table 2).

Absolute DLCO differed significantly among groups (p = 0.001): 9.56 ± 1.55 mmol/min/kPa in controls, 11.22 ± 1.91 mmol/min/kPa in runners, and 10.28 ± 0.91 mmol/min/kPa in tennis players. Post hoc analysis showed higher absolute DLCO in runners than controls (p < 0.001) (Table 2). Neither the runner-tennis (p = 0.079) nor tennis-control comparison (p = 0.223) reached significance (Table 3). Percent-predicted DLCO showed a similar pattern: 95 ± 13% in controls, 113 ± 22% in runners, and 106 ± 10% in tennis players (p < 0.001) (Table 3). Only the runner-control comparison was significant (p < 0.001); the tennis-control comparison yielded p = 0.064 (Table 3).

Absolute VA differed among groups (p = 0.006): 5.11 ± 0.79 L in controls, 5.83 ± 0.94 L in runners, and 5.23 ± 0.73 L in tennis players (Table 2). Runners had higher absolute VA than controls (p = 0.008) and tennis players (p = 0.030) (Table 3). Percent-predicted VA was 90 ± 12%, 104 ± 20%, and 96 ± 13%, respectively (p = 0.009) (Table 2), with a significant runner-control difference (p = 0.007) (Table 3). Absolute KCO was comparable across groups (1.88 ± 0.22, 1.94 ± 0.26, and 1.99 ± 0.25 mmol/min/kPa/L; p = 0.286), as was percent-predicted KCO (106 ± 12%, 109 ± 15%, and 111 ± 14%; p = 0.379) (Table 2).

Table 2. The Comparison of Lung Function Parameters Between Groups

Variables	Control Mean±SD	Running Mean±SD	Tennis Mean±SD	p-value
VC Predicted	4.70±0.27	4.67± 0.37	4.53±0.25	0.272[b]
VC (L)	3.98±0.37	4.08±0.82	3.99±0.45	0.788[a]
VC (%)	0.85±0.05	0.88±0.18	0.88±0.09	0.537[a]
FVC Predicted	4.90± 0.31	4.91±0.37	4.75±0.27	0.193[b]
FVC (L)	4.18±0.43	4.48±0.82	4.48±0.47	0.134[a]
FVC (%)	0.85±0.06	0.91±0.16	0.94±0.07	0.013[a]*

FEV1 Predicted	4.18±0.26	4.19±0.28	4.07±0.21	0.171[b]
FEV1 (L)	3.52±0.33	3.90±0.74	3.86±0.37	0.022[a]*
FEV1 (%)	0.84±0.06	0.93±0.17	0.95±0.06	0.002[a]*
FEV1/FVC (%)	0.84±0.04	0.87±0.07	0.86±0.04	0.035[b]*
DLCO Predicted	10.02±0.52	10.00±0.65	9.73±0.46	0.187[b]
DLCO (mmol/min/kPa)	9.56±1.55	11.22±1.91	10.28±0.91	0.001[a]*
DLCO (%)	0.95±0.13	1.13±0.22	1.06±0.10	<0.001[b]*
KCO Predicted	1.78±0.19	1.78±0.03	1.79±0.02	0.393[b]
KCO (mmol/min/kPa/L)	1.88±0.22	1.94±0.26	1.99±0.25	0.286[a]
KCO (%)	1.06±0.12	1.09±0.15	1.11±0.14	0.379[a]
VA Predicted	5.64±0.35	5.64±0.45	5.44±0.31	0.148[b]
VA (L)	5.11±0.79	5.83±0.94	5.23±0.73	0.006[a]*
VA (%)	0.90±0.12	1.04±0.20	0.96±0.13	0.009[a]*

*[a]One-way ANOVA analysis; [b]Kruskal-Wallis analysis; *statistically significant (p<0.05). DLCO= Diffusing capacity of the lung for carbon monoxide; VA= Alveolar volume; FVC= Forced vital capacity; FEV1= Forced expiratory volume in 1 second; KCO= Krogh factor.*

Table 3. Post-Hoc Analysis of Lung Function Between Two Groups

Variables	Running vs Control	Tennis vs Control	Running vs Tennis
VC (L)[a]	0.814	1.000	0.829
VC (%)[a]	0.672	0.545	0.977
FVC (L)[a]	0.194	0.187	1.000
FVC (%)[a]	0.114	**0.011***	0.608
FEV1 (L)[a]	**0.031***	0.061	0.956
FEV1 (%)[a]	**0.014***	**0.004***	0.898
FEV1/FVC (%)[b]	**0.031***	0.542	0.654
DLCO (mmol/min/kPa)[a]	**<0.001***	0.223	0.079
DLCO (%)[b]	**<0.001***	0.064	0.376
KCO (mmol/min/kPa/L)[a]	0.689	0.254	0.721
KCO (%)[a]	0.716	0.347	0.811
VA (L)[a]	**0.008***	0.870	**0.030***
VA (%)[a]	**0.007***	0.379	0.176

*[a]Tukey HSD test; [b] Mann-Whitney test with Bonferroni correction; * statistically significant (p<0,05).*

3.3 The DLCO Analysis

After adjustment for age, BMI, Brinkman Index, and hemoglobin, the overall ANCOVA model for percent-predicted DLCO was significant ($p < 0.001$; $R^2 = 0.361$; adjusted $R^2 = 0.304$). Runners had higher percent-predicted DLCO than controls (B = 0.164; 95% CI, 0.074 to 0.254; $p < 0.001$; partial $\eta^2 = 0.163$), whereas the tennis-control difference did not reach significance (B = 0.084; 95% CI, -0.002 to 0.170; p = 0.056). Age (B = -0.034; 95% CI, -0.053 to -0.014; p = 0.001) and hemoglobin (B = -0.038; 95% CI, -0.066 to -0.010; p = 0.008) were negatively associated with percent-predicted DLCO; BMI and Brinkman Index were not significant. Levene's test indicated heteroscedasticity ($p < 0.001$) (Table 4). In the Quade nonparametric ANCOVA sensitivity analysis, the overall group difference remained significant (p = 0.020); percent-predicted DLCO was higher in runners (p = 0.008) and tennis players (p = 0.032) than controls, with no difference between the exercise groups (p = 0.603) (Table 4).

Table 4. ANCOVA and Quade Non-Parametric ANCOVA Analysis to DLCO (%)

Variables	B	95% CI	Partial η^2	p-value
Umur	−0.034	−0.053 – −0.014	0.146	0.001
BMI	0.001	−0.011 – 0.012	0.000	0.927
Brinkman index	−0.001	−0.009 – 0.007	0.002	0.723
Hb	−0.038	−0.066 – −0.010	0.098	0.008
Running vs Control	0.164	0.074 – 0.254	0.163	**<0.001***
Tennis vs Control	0.084	−0.002 – 0.170	0.053	0.056
Intercept	2.188	1.520 – 2.857	0.385	<0.001
Quade Non-Parametric ANCOVA Analysis				
(I) Groups	**(J) Groups**	**95% CI**		**p-value**
Running	Control	0.053 – 0.274		**0.008***
Running	Tennis	−0.021 – 0.181		0.603
Tennis	Control	—[c]		**0.032***

*B= Non-standardized regression coefficients; CI= Confidence interval; η^2= Eta-squared (partial effect size); * significant (p< 0.05). Overall p value < 0,001; R^2= 0.361; Adjusted R^2= 0.304; Levene's test p<0.001. Estimated Marginal Means (adjusted): Running= 1.127 (95% CI: 1.068–1.187); Tennis= 1.047 (95% CI: 0.989–1.105); Control= 0.963 (95% CI: 0.902–1.025).*

*Overall Quade Non-Parametric ANCOVA: F(2.72)= 4.147; p= 0.020. *statistically significant (p<0.05). [c] Confidence interval is not available from the analysis output for this comparison*

The overall ANCOVA model for percent-predicted VA was also significant (p = 0.001; $R^2 = 0.271$; adjusted $R^2 = 0.207$). After adjustment, runners had higher percent-predicted VA than controls (B = 0.125; 95% CI, 0.035 to 0.215; p = 0.007; partial $\eta^2 = 0.101$), whereas tennis players did not differ from controls (B = 0.045; 95% CI, -0.041 to 0.131; p = 0.303). Age (B = -0.027; 95% CI, -0.047 to -0.008; p = 0.008) and hemoglobin (B = -0.032; 95% CI, -0.060 to -0.004; p = 0.025) were negatively associated with percent-predicted VA; BMI and Brinkman Index were not significant. Levene's test indicated heteroscedasticity (p = 0.046). Quade nonparametric ANCOVA did not show a significant overall group difference (p = 0.089) (Table 5). Although the runner-control pairwise comparison yielded p = 0.029, this result should be interpreted cautiously because the

omnibus test was not significant; the runner-tennis (p = 0.196) and tennis-control comparisons (p = 0.358) were also nonsignificant (Table 5).

Table 5. ANCOVA and Quade Non-Parametric ANOVA Analysis to VA (%)

Variables	B	95% CI	Partial η^2	p-value
Ages	−0.027	−0.047 – −0.008	0.100	0.008
BMI	0.002	−0.010 – 0.013	0.002	0.746
Brinkman index	0.003	−0.005 – 0.011	0.010	0.404
Hb	−0.032	−0.060 – −0.004	0.071	0.025
Running vs Control	0.125	0.035 – 0.215	0.101	**0.007***
Tennis vs Control	0.045	−0.041 – 0.131	0.016	0.303
Intercept	1.885	1.213 – 2.556	0.316	<0.001
Quade Non-Parametric Analysis				
(I) Groups	**(J) Groups**	**95% CI**		**p-value**
Running	Control	0.014 – 0.236		**0.029***
Running	Tennis	−0.021 – 0.182		0.196
Tennis	Control	−0.061 – 0.151		0.358

**significant (p<0,05). Overall p value= 0,001; R^2= 0.271; Adjusted R^2= 0.207; Levene's test p= 0.046.*

*Overall Quade Non-Parametric ANCOVA: F(2.72)= 2.732; p= 0.089. *significant (p<0.05).*

3.4 Discussion

Running, tennis, and control participants displayed different pulmonary function profiles across ventilatory and diffusing-capacity domains. The most consistent between-group signal involved DLCO in runners, whereas most measures were comparable between runners and tennis players. Thus, the findings do not support the overall superiority of either sport but suggest distinct physiological profiles relative to controls.

Age, height, hemoglobin, and smoking exposure were broadly comparable across groups, whereas controls had higher weight and BMI. The relationship between BMI and pulmonary function is complex and varies by BMI range and population characteristics [7]. Adjusting the DLCO and VA models for BMI reduced the likelihood that diffusion differences merely reflected body size. BMI was not adjusted for in the spirometric analyses, however, leaving potential residual influence on ventilatory measures. Training exposure also differed, runners trained more frequently, whereas tennis players had longer sessions and greater weekly volume. The contribution of exercise modality therefore cannot be fully separated from training frequency and duration.

Percent-predicted FEV1 was higher in runners and tennis players than controls. The percent-predicted FVC difference was driven mainly by tennis players versus controls, whereas absolute FEV1 and FEV1/FVC differed primarily between runners and controls. Absolute VC, percent-predicted VC, and absolute FVC were comparable across groups. These findings indicate parameter-specific associations between exercise and ventilatory function. FEV1, FVC, and FEV1/FVC should also be interpreted against reference equations and lower limits of normal rather than group means alone [1]. The present results therefore more likely reflect physiological variation in healthy individuals than clinically meaningful ventilatory impairment.

The literature is similarly heterogeneous. Rajaure et al. reported no FVC or FEV1 differences between aerobic and anaerobic athletes, although several flow and maximal ventilation measures differed.[6] By contrast, a short aerobic intervention in

untrained young adults increased FEV1 and FVC [8]. In the UK Biobank cohort, persistently low physical activity was associated with faster longitudinal declines in FEV1 and FVC [9]. Differences in design, baseline fitness, and exposure duration may account for these divergent findings. Evidence for structural pulmonary remodeling after chronic training remains limited; higher spirometric values in athletes do not, by themselves, establish structural adaptation [3].

Between-group differences were more apparent for diffusing capacity. DLCO was numerically highest in runners, followed by tennis players and controls. Runners also had higher absolute VA than both other groups, while the percent-predicted VA difference was driven mainly by the runner-control comparison. KCO was comparable across groups. DLCO must be interpreted alongside VA and KCO: VA reflects the lung volume participating in the maneuver, whereas KCO expresses gas transfer relative to VA. Their relationship is not linear because KCO depends on the lung volume at which it is measured. KCO should therefore not be regarded as a stand-alone measure of alveolar-capillary membrane efficiency [1].

In runners, higher DLCO occurred with greater VA but unchanged KCO, suggesting that the lung volume participating in the maneuver contributed to DLCO. Greater VA, however, does not equate to a larger anatomical alveolar surface area, and similar KCO does not establish equivalent pulmonary membrane or vascular function. During exercise, increased ventilation and pulmonary blood flow promote pulmonary capillary recruitment and distension [2]. Interventional evidence indicates that high-intensity endurance training can increase TLCO, TLNO, membrane diffusing capacity (DM), and pulmonary capillary blood volume (Vc) in young athletes [4]. Endurance-trained individuals have also shown higher resting DLCO and greater microvascular recruitment than untrained individuals [10]. These data support the physiological plausibility of the runner findings but do not establish training as their cause.

Findings in the tennis group were more sensitive to the analytical method. DLCO was numerically higher than in controls but was nonsignificant in parametric post hoc testing and only approached significance after covariate adjustment. Quade analysis, however, showed higher percent-predicted DLCO in tennis players than controls. Court-based interval training improves aerobic capacity and tennis-specific endurance, but the relevant study did not measure DLCO.[6] In another intermittent sport, soccer training increased TLCO, DM, and Vc without a significant change in VA in boys.[11] This offers indirect physiological support but cannot define the mechanism in tennis players. Between-sport heterogeneity in DLCO has also been reported among aquatic athletes, although observational studies cannot separate training effects from athlete selection [12].

Direct comparison of runners and tennis players showed no differences in DLCO or KCO; the principal difference was confined to absolute VA. After covariate adjustment, the association between running and percent-predicted DLCO remained consistent in nonparametric analysis. In contrast, the percent-predicted VA difference was not supported by the Quade omnibus test, warranting conservative interpretation of the runner-control pairwise result. Age and hemoglobin were negatively associated with percent-predicted DLCO and VA, but these directions should not be interpreted as biological mechanisms. Predicted percentages already incorporate age, and the methods did not specify whether DLCO was corrected for hemoglobin [1]. Hemoglobin does not directly determine VA; its association with percent-predicted VA should therefore be regarded as statistical and requires confirmation. BMI and Brinkman Index made no independent contribution to either model, although low smoking exposure and unequal smoker distribution leave residual confounding possible.

This study integrated spirometry with DLCO, VA, and KCO, adjusted for relevant confounders, and included sensitivity analyses. Limitations include the cross-sectional design, unequal training doses, absence of maximal oxygen uptake (VO_2max), lack of BMI adjustment in spirometric analyses, heteroscedasticity, and no direct measurement of DM or Vc. Recruitment from different sources and restriction to young adult men further limit inference and generalizability. Clinically, these results are best understood as variation in resting pulmonary function phenotypes among healthy individuals rather than evidence of direct clinical benefit. Longitudinal studies using standardized training doses, objective fitness measures, and direct assessment of DM and Vc are needed.

4. CONCLUSION

Pulmonary function profiles differed among young adult male runners, tennis players, and controls. Runners and tennis players had broadly comparable pulmonary function across most measures, with the clearest between-sport difference involving alveolar volume. DLCO and VA differed among individual, whereas KCO did not. Runners had higher DLCO than controls alongside greater VA; the direct runner-tennis difference was primarily confined to absolute VA.

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AUTHOR CONTRIBUTIONS

Amalia M Akib: Conceptualization, investigation, methodology, data analysis, data interpretation, Writing - Drafting.

Nur Ahmad Tabri: Conceptualization, investigation, methodology, data interpretation.

Harry Akza Putrawan: Data interpretation, methodology, and supervision

Irawaty Djaharuddin: Data interpretation, supervision, and writing—Review & Editing

Muh Ilyas: Supervision and writing—Review & Editing

Bulkis Natsir: Supervision and writing—Review & Editing

Edward Pandu Wiriansya: Supervision and writing—Review & Editing.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ETHICS STATEMENT

The study was approved by the Health Research Ethics Committee of the Faculty of Medicine, Hasanuddin University (186/UN.4.6.4.5.31/ PP36/ 2026). All participants provided written informed consent, and the study was conducted in accordance with the Declaration of Helsinki.

DATA AVAILABILITY STATEMENT

The data were available by requests.

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