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Spirometry Testing and its Relationship with Hand Grip Strength in Well-controlled Type 2 Diabetes Patients

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Abstract

Introduction: The muscle-lung axis demonstrates a synchronized decline in peripheral physical performance and respiratory mechanics in metabolic diseases. This study evaluated the relationship between spirometry parameters and handgrip strength in patients with well-controlled type 2 diabetes mellitus to clarify its utility as a clinical marker for early respiratory frailty.

Methods: A cross-sectional study was conducted on 80 participants (25 males and 55 females) with good glycemic control, defined as a HbA1c level below 7%. Peripheral muscle strength was quantified using dominant and non-dominant isometric handgrip strength. Objective respiratory evaluation included peak expiratory flow rate, forced expiratory volume in one second, and forced vital capacity. Raw lung volumes were transformed into multi-ethnic standardized Z-scores using the Global Lung Function Initiative reference equations.

Results: Converting raw lung volumes into standardized Z-scores completely eliminated baseline biological sex-specific variations. Dominant handgrip strength correlated strongly with peak expiratory flow rate, while non-dominant handgrip strength exhibited a significant positive linear relationship with standardized lung volumes. One-way analysis of variance demonstrated that a longer duration of diabetes was associated with a significant, progressive decline in standardized lung volumes, whereas peripheral skeletal muscle strength remained stable across the four distinct disease-duration cohorts (<1 year, 1-5 years, 5-10 years, and >10 years). In multivariate linear regression modeling, dominant handgrip strength emerged as the strongest independent positive predictor of the standardized forced expiratory volume in one second Z-score, operating independently of age, height, biological sex, or disease.

Conclusion: Peripheral muscle strength is positively associated with standardized respiratory parameters in patients with well-controlled type 2 diabetes mellitus. Furthermore, longer disease duration is associated with lower standardized lung volumes, whereas peripheral muscle strength remains preserved across disease-duration cohorts. Handgrip dynamometry offers a rapid, non-invasive clinical screening tool to detect early subclinical respiratory decline.

Keywords: Glycemic control, handgrip strength, muscle-lung axis, peak expiratory flow rate, respiratory frailty, spirometry, type 2 diabetes

1. Introduction

Type 2 diabetes mellitus (T2DM) is a global health challenge, historically recognized for its microvascular and macrovascular complications, including retinopathy, nephropathy, neuropathy, and

cardiovascular disease^{1,2}. However, evidence demonstrates that chronic hyperglycemia impacts systems beyond traditional targets, with the lung emerging as an overlooked target organ³⁻⁵.

Despite its vast microvascular reserve, the pulmonary system undergoes silent pathological changes in T2DM prior to clinical symptoms,

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characterized by progressive restrictive impairment and reduced gas exchange efficiency⁶⁻⁸. Molecularly, chronic blood glucose exposure accelerates non-enzymatic glycation, leading to tissue deposition of advanced glycation end-products (AGEs)⁹. These AGEs form irreversible cross-links with structural collagen and elastin, reducing parenchymal compliance and stiffening the thoracic cage¹⁰. Simultaneously, chronic hyperglycemia triggers low-grade systemic inflammation and endothelial dysfunction, driving basement membrane thickening within the alveolar-capillary network. This microangiopathy impairs pulmonary diffusing capacity (DL_{CO}) and restricts forced expiratory volumes^{11,12}.

Parallel to this pulmonary degradation, T2DM is known to induce skeletal muscle dysfunction, a phenomenon increasingly characterized as *diabetic myopathy*^{13,14}. This muscular impairment is driven by insulin resistance, mitochondrial dysfunction, altered protein turnover, and intramyocellular lipid accumulation, resulting in a profound loss of muscle quality, structural integrity, and force-generating capacity^{15,16}. Crucially, this metabolic myopathy is not limited to limb muscles alone; it affects the primary and accessory muscles of respiration, including the diaphragm and the intercostal muscles^{17,18}. The synchronized deterioration of skeletal muscle performance and pulmonary mechanics has given rise to the concept of the *muscle-lung axis* in metabolic diseases¹⁹. In this axis, a decline in peripheral muscle mass and strength frequently serves as a proxy marker for an unseen, parallel weakness in the respiratory pump^{20,21}.

While the clinical utility of spirometry testing is undeniable for quantifying declines in forced expiratory volume in one second (FEV1) and forced vital capacity (FVC), traditional raw volumetric outputs often fail to isolate the true systemic impact of diabetes due to confounding demographic factors like age, height, and biological sex²². To overcome this limitation, contemporary respiratory research utilizes standardized Z-scores benchmarked against the Global Lung Function Initiative 2012 (GLI-2012) multi-ethnic reference equations²³. Standardizing raw data into Z-scores establishes a clean, modern comparative metric that effectively removes demographic biases, allowing for a precise evaluation of diabetes-driven respiratory impairment²⁴.

Furthermore, while severe pulmonary and muscular declines are well-documented in poorly controlled, highly hyperglycemic diabetic populations, a significant clinical gap remains regarding whether these structural alterations progress when a patient maintains stable, tight glycemic control²⁵. By utilizing a highly precise Lafayette hand dynamometer to evaluate peripheral muscle capacity alongside GLI-2012 spirometric Z-scores, this study aims to clarify the specific dynamics of the muscle-lung axis in patients with well-controlled T2DM (HbA1c < 7%). Specifically, this paper evaluates the relationship between respiratory performance and peripheral muscle strength across both dominant and non-dominant upper extremities to evaluate its clinical utility as a non-invasive marker for early respiratory frailty.

2. Methods

2.1. Study design and participant selection

This cross-sectional study analyzed baseline data from an interventional clinical trial conducted at the Diabetic Clinic of National Hospital Galle. The sample size (n=80) was calculated based on the primary interventional endpoint of the main trial. A total of 80 participants (25 males and 55 females) were recruited via convenience sampling. Inclusion criteria required stable, well-controlled glycemia, defined as a documented HbA1c level below 7%²⁶. Exclusion criteria comprised primary obstructive or restrictive pulmonary pathologies, such as bronchial asthma, chronic obstructive pulmonary disease (COPD), idiopathic pulmonary fibrosis, or active respiratory infections. Other exclusion criteria included history of cigarette smoking, or

upper extremity neuromuscular, orthopedic, or arthritic conditions interfering with maximal isometric handgrip testing²⁷.

2.2. Anthropometric and clinical baseline assessments

Standardized anthropometric measurements were collected prior to physical performance testing. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer, and body mass to the nearest 0.1 kg using a calibrated digital medical scale. Chronological age and time since initial T2DM diagnosis were extracted from medical records. Diabetes duration was categorized into four groups: Group 1 (<1 year), Group 2 (1-5 years), Group 3 (5-10 years), and Group 4 (>10 years).

2.3. Musculoskeletal assessment and hand dominance mapping

Peripheral skeletal muscle strength was quantified via isometric handgrip strength (HGS) testing using a calibrated (resolution 2 kg) Lafayette hand dynamometer (Lafayette, IN, USA). Hand dominance was established and coded (1: right-hand dominant; 2: left-hand dominant)²⁸. Following American Society of Hand Therapists (ASHT)²⁹ guidelines, participants were seated with the shoulder adducted, elbow flexed at 90°, and forearm in neutral position³⁰. Participants exerted maximum isometric force for 3 seconds. Three alternating trials per hand were recorded with a mandatory 60-second rest period between efforts³¹. The maximum peak force (kg) was recorded for each hand. Peak force from the preferred limb defined dominant handgrip strength (DHGS), while force from the non-preferred limb defined non-dominant handgrip strength (NDHGS). Variable coding was executed in IBM SPSS Statistics for Windows, version 26.0 (IBM Corp., Armonk, NY, USA).

2.4. Spirometric lung function evaluation

Spirometry was conducted using a COSMED Pony FX lung function machine to measure FEV1, FVC, the unadjusted FEV1/FVC ratio, and peak expiratory flow rate (PEFR). Testing followed American Thoracic Society (ATS) / European Respiratory Society (ERS)³² technical standards. Participants performed at least three acceptable forced expiratory maneuvers while wearing a nose clip, with peak reproducible values recorded. To eliminate demographic confounding from anatomical sizing, raw volumes FEV1 and FVC were converted into standardized Z-scores using GLI-2012 multi-ethnic reference equations. These Z-scores express measured volumes as standard deviations from expected healthy population means, adjusting for age, sex, height, and ethnicity²³. It expresses an individual's measured lung volume as the number of standard deviations away from the expected mean of a healthy population, fully accounting for variations in age, biological sex, height, and ethnic background, thereby eliminating demographic bias.

2.5. Statistical analysis matrix

Statistical analysis was performed using IBM SPSS Statistics (Version 26.0) with significance set a priori at $\alpha=0.05$. Normality of continuous variables was assessed using Shapiro-Wilk tests, histograms, and Q-Q plots³³.

2.5.1. Descriptive and baseline analysis

Continuous normal parametric variables (age, height, right HGS, left HGS, PEFR, FEV1 Z-scores, FVC Z-scores) were compared between biological sexes using independent-samples t-test.

2.5.2. Bivariate correlations

Parametric Pearson correlation coefficients (*r*) evaluated associations between normally distributed parameters FEV1 Z-score, FVC Z-score, PEFR, DHGS, NDHGS). Because the FEV1/FVC ratio deviated from normality ($p=0.044$), non-parametric Spearman's correlation (ρ) and Mann-Whitney U tests were applied.

2.5.3. Disease duration variance

One-way analysis of variance (ANOVA) evaluated FEV1 Z-scores, FVC Z-scores, right HGS, and left HGS across the four duration cohorts, followed by Tukey's HSD post-hoc testing for significant models.

2.5.4. Multivariate regression

Multiple linear regression was conducted with standardized FEV1 Z-score as the continuous dependent variable. Independent predictors entered simultaneously were age, sex, height, diabetes duration, and DHGS. Multicollinearity was evaluated using variance inflation factors

(VIF) and tolerance statistics.

3. Results

3.1. Cohort demographics and anthropometric disparities

The study cohort comprised 80 patients diagnosed with T2DM, stratified into 25 male participants (31.25%) and 55 female participants (68.75%). All individuals within this sample population exhibited well-controlled glycemia, maintaining an HbA1c threshold below 7.0%. The demographic and anthropometric details are presented in Table 1.

Table 1: Baseline demographic and anthropometric characteristics stratified by biological sex

Parameter	Male (n=25)	Female (n=55)	Total Cohort (N=80)	Test Statistic (t-value)	p-value
Sex distribution n (%)	25 (31.25)	55 (68.75)	80 (100)	—	—
Glycemic control (HbA1c)	<7.0%	<7.0%	<7.0%	—	—
Age (years)	58.81 ± 6.75	54.44 ± 8.53	—	t (78)=2.29	0.025*
Height (cm)	167.19 ± 5.96	153.87 ± 5.96	—	t (78)=8.65	<0.001*

*Significant at $p < 0.05$. Data presented as mean ± SD for continuous variables and n (%) for categorical variables. Degrees of freedom for independent-samples t-tests equal 78. HbA1c: glycated hemoglobin

3.2. Raw physical performance vs standardized pulmonary metrics

Evaluation of peripheral musculoskeletal strength and unadjusted respiratory flow rates revealed prominent sex-specific variations.

3.2.1. Muscular strength profile

Males exhibited significantly higher raw handgrip strength than females across both upper extremities. Right handgrip strength was measured at 28.27 ± 5.56 kg for males compared to 19.22 ± 4.88 kg for females ($t(78)=7.35$, $p < 0.001$). Similarly, left handgrip strength was substantially greater in the male cohort (29.54 ± 5.21 kg) relative to the female cohort (18.24 ± 5.87 kg) ($t(78)=8.35$, $p < 0.001$).

3.2.2. Volumetric peak expiratory flow

Unadjusted dynamic respiratory power, assessed by PEFR, demonstrated a profound male advantage, with men reaching a mean flow of 6.98 ± 1.63 L/s compared to the female mean of 4.40 ± 1.22 L/s ($t(78)=7.90$, $p < 0.001$).

3.2.3. Standardized pulmonary parity

In stark contrast to the unadjusted physical markers, when raw lung volumes were converted to multi-ethnic standardized Z-scores using the GLI-2012 framework all sexual dimorphism was entirely eliminated. The FEV1 Z-scores for males (mean: -1.39 ± 0.62) were statistically identical to those of females (mean: -1.39 ± 1.06) ($t(78) = -0.03$, $p = 0.980$). This uniform impairment pattern extended to FVC Z-scores, where no significant difference was observed between the male mean (-1.43 ± 0.76) and female mean (-1.49 ± 1.07) ($t(78) = 0.24$, $p = 0.814$). This finding establishes that the proportional impact of chronic T2DM on lung parenchyma and thoracic volumes operates uniformly across genders when adjusted for baseline body size.

3.3. Bi-limb correlation matrix and the muscle-lung axis

To rigorously map the muscle-lung axis, bivariate correlation matrices were constructed utilizing a hybrid statistical methodology dictated by data normality distribution patterns (Table 2).

3.4. Impact of disease duration: lungs vs muscle

The impact of disease duration on pulmonary function and skeletal muscle strength has been presented in Table 3.

3.5. Multiple linear regression model

An examination of individual standardized regression coefficients isolated the unique independent predictive weight of each element (Table 4).

3.5.1. Dominant musculoskeletal strength

DHGS emerged as the strongest and most highly significant independent positive predictor of standardized lung volume within

the multivariate environment ($\beta = 0.406$, $B = 0.056$, $SE = 0.021$, $t = 2.72$, $p = 0.008$). This demonstrates that for every one-kilogram increase in dominant handgrip force, the standardized FEV1 Z-score increases by 0.056 units, entirely independent of the patient's age, sex, height, or duration of diabetes.

3.5.2. Chronological age

Age also functioned as a highly significant independent predictor within the model, displaying a positive weight association ($\beta = 0.384$, $B = 0.044$, $SE = 0.014$, $t = 3.24$, $p = 0.002$).

Table 2: Parametric and non-parametric correlation matrix within the muscle-lung axis (n=80)

Variable Pair	Analysis Method	Correlation Coefficient	p-value
<i>Dominant HGS vs dynamic flow</i>			
Dominant HGS vs PEFR	Pearson (r)	$r = 0.408$	$< 0.001^*$
<i>Dominant HGS vs standardized volumes</i>			
Dominant HGS vs FEV1 Z-score	Pearson (r)	$r = 0.132$	0.243
Dominant HGS vs FVC Z-score	Pearson (r)	$r = 0.160$	0.156
<i>Non-dominant HGS vs standardized volumes</i>			
Non-dominant HGS vs FEV1 Z-score	Pearson (r)	$r = 0.237$	0.034*
Non-dominant HGS vs FVC Z-score	Pearson (r)	$r = 0.262$	0.019*
<i>Spirometric volume and ratio relationship</i>			
FEV1 Z-score vs FEV1/FVC ratio	Spearman (ρ)	$\rho = 0.255$	0.022*

*Significant at $p < 0.05$. HGS: handgrip strength; PEFR: peak expiratory flow rate; FEV1: forced expiratory volume in one second; FVC: forced vital capacity. Z-scores derived from GLI-2012 multi-ethnic reference equations. Pearson product-moment correlation coefficient (r) used for normally distributed parameters. Spearman's rank-order correlation coefficient (ρ) used for non-normally distributed parameters. Mann-Whitney U test for sex differences in FEV1/FVC ratio yielded $U = 699.5$, $p = 0.992$.

Table 3: One-way ANOVA of pulmonary Z-scores and muscle strength across disease duration cohorts (n=80)

Parameter	Group 1 (<1 year) (n=12)	Group 2 (1-5 years) (n=28)	Group 3 (5-10 years) (n=22)	Group 4 (>10 years) (n=18)	F-statistic (df=3,76)	p-value	Post-Hoc Comparison
<i>Pulmonary metrics</i>							
FEV1 Z-score	-0.92 ± 0.78	-1.31 ± 0.89	-1.49 ± 0.98	-1.71 ± 0.99	$F = 2.79$	0.046*	Progressive linear decline
FVC Z-score	-0.95 ± 0.81	-1.41 ± 0.92	-1.59 ± 1.01	-1.76 ± 0.98	$F = 2.93$	0.039*	Progressive linear decline
<i>Skeletal muscle strength</i>							
Dominant HGS (kg)	22.50 ± 6.12	21.82 ± 6.45	22.14 ± 6.88	21.90 ± 6.30	$F = 0.28$	0.843	All pairwise $p > 0.80$
Non-dominant HGS (kg)	22.10 ± 6.80	21.45 ± 7.10	22.10 ± 8.20	21.20 ± 7.90	$F = 0.68$	0.566	All pairwise $p > 0.80$

*Significant at $p < 0.05$. Data presented as mean ± SD. Degrees of freedom (df) for all models=3,76. HGS: handgrip strength; FEV1: forced expiratory volume in one second; FVC: forced vital capacity. Z-scores derived from GLI-2012 multi-ethnic reference equations. Post-hoc analysis conducted by Tukey's honestly significant difference (HSD) test

Table 4: Multiple linear regression model predicting standardized FEV1 Z-score (n=80)

Predictor Variable	Unstandardized Coefficient (B)	Standard Error	Standardized Coefficient (β)	t-statistic	p-value	95% CI (B)
Constant	3.120	1.850	—	1.687	0.096	$-0.566, 6.806$
Dominant HGS (kg)	0.056	0.021	0.406	2.720	0.008*	0.015, 0.097
Age (years)	0.044	0.014	0.384	3.240	0.002*	0.017, 0.071
Height (cm)	-0.034	0.016	-0.327	-2.160	0.034*	$-0.065, -0.003$
Biological Sex (Male = 1)	0.265	0.369	0.129	0.718	0.475	$-0.470, 1.000$
Diabetes Duration (years)	-0.012	0.020	-0.069	-0.592	0.556	$-0.052, 0.028$

*Significant at $p < 0.05$. $R = 0.451$, $R^2 = 0.203$, Adjusted $R^2 = 0.149$; $F(5,74) = 3.77$; $p = 0.004$. Dependent variable: GLI-2012 standardized FEV1 Z-score. HGS: handgrip strength

3.5.3. Structural height

Height maintained a significant negative predictive association with the standardized Z-score output ($\beta = -0.327$, $B = -0.034$, $SE = -0.016$, $t = -2.16$, $p = 0.034$).

3.5.4. Covariate independence

Crucially, within this multi-variable framework, both biological sex ($\beta = 0.129$, $p = 0.475$) and chronological duration of T2DM ($\beta = -0.069$, $p = 0.556$) completely lost their predictive significance.

4. Discussion

The findings of this cross-sectional study support the existence of a functional relationship within the muscle-lung axis in patients with well-controlled T2DM ($HbA1c < 7\%$). By utilizing standardized GLI-2012 spirometric Z-scores and precision hand dynamometry, these results extend previous observations by confirming that peripheral muscle strength correlates with standardized pulmonary function even in the absence of overt, acute hyperglycemia.

The positive association observed between DHGS and standardized FEV1 Z-scores ($\beta = 0.406$, $p = 0.008$) aligns with prior literature, reporting concurrent declines in peripheral skeletal muscle capacity and pulmonary mechanics in metabolic disease^{5,7}. Because FEV1 is an effort-dependent volumetric metric requiring rapid force generation from thoracic respiratory muscles, peripheral hand dynamometry may serve as an accessible surrogate marker for overall neuromuscular capacity²⁰. These findings confirm previous reports linking non-enzymatic glycation and AGE accumulation with reduced parenchymal compliance and thoracic cage stiffness in diabetic cohorts^{8,12}. However, unlike earlier studies focused on poorly controlled diabetic populations, our findings indicate that subclinical restrictive patterns (reduced FEV1 and FVC Z-scores) remain observable in patients maintaining stable glycemic control $HbA1c < 7\%$ ^{11,34}.

An important observation in our correlation matrix was the divergence between upper extremities. While dominant HGS correlated strongly with dynamic peak flow (PEFR: $r = 0.408$, $p < 0.001$), non-dominant HGS exhibited stronger, statistically significant linear correlations with standardized pulmonary volumes (FEV1 Z-score: $r = 0.237$; FVC Z-score: $r = 0.262$). This discrepancy can be contextualized through established neuromuscular principles. The dominant hand is subject to neural adaptation and conditioning from routine daily activities²⁹, which may transiently mask underlying metabolic myopathy²⁸. In contrast, non-dominant limb strength may better reflect baseline systemic muscle quality. Conversely, dominant HGS captures peak voluntary recruitment, explaining its stronger association with explosive expiratory maneuvers (PEFR). Evaluating both limbs provides a more comprehensive assessment of systemic physical capacity^{30,35}.

One-Way ANOVA revealed that while standardized FEV1 and FVC Z-scores were significantly lower across longer diabetes duration categories ($p = 0.046$ and $p = 0.039$, respectively), handgrip strength showed no significant variance across duration groups. This divergence supports the hypothesis that pulmonary microvascular bed vulnerability may precede overt peripheral muscle weakness. The pulmonary alveolar-capillary network possesses an extensive microvascular surface area that is particularly susceptible to low-grade inflammation, basement membrane thickening, and altered DL_{CO} ^{6,36,37}. In contrast, peripheral skeletal muscle groups benefit from ongoing mechanical loading during daily locomotion, preserving gross force production during early-to-mid disease stages^{7,15,38}. Consequently, subclinical pulmonary volume loss may present as an earlier indicator of diabetic organ involvement than peripheral handgrip decline.

From a clinical perspective, handgrip dynamometry offers a practical, objective, and low-cost tool to screen for generalized physical

weakness in outpatient settings. Identifying low handgrip performance could prompt earlier referral for formal spirometry or preventative pulmonary rehabilitation. However, these findings must be interpreted with caution. Although dominant HGS was an independent predictor in multivariable linear regression, the overall model explained only 20.3% of the variance in FEV1 Z-scores ($R^2 = 0.203$, Adjusted $R^2 = 0.149$). This indicates that nearly 80% of the variability in lung function is driven by unmeasured physiological, metabolic, or structural factors. Handgrip strength should therefore be viewed as an adjunct screening tool rather than a substitute for diagnostic spirometry.

5. Limitations of the Study

The cross-sectional nature of this study precludes any temporal or causal inferences regarding disease progression. Also, participants were recruited via convenience sampling from a single tertiary care institution, which introduces potential selection bias and limits external validity across broader diabetic populations. Moreover, the sample size ($n = 80$) was derived from the primary interventional endpoint of a parent clinical trial, and an a priori power calculation was not performed specifically for this cross-sectional secondary analysis. There were also confounding variables, including body mass index (BMI), waist circumference, physical activity levels, nutritional status, sarcopenia, diabetic neuropathy, medication profiles, and cardiovascular or renal comorbidities, which were not adjusted for in the multivariable models, leaving open the possibility of residual confounding. Additionally, direct measures of respiratory muscle force (maximal inspiratory and expiratory pressures, $P_{I_{max}}$ and $P_{E_{max}}$) and pulmonary gas-exchange efficiency via diffusing capacity (DL_{CO}) were not performed.

6. Conclusion

The study supports the presence of an association between peripheral handgrip strength and standardized spirometric volumes in patients with well-controlled T2DM. Handgrip strength may serve as an accessible clinical surrogate marker for screening respiratory status. However, given the cross-sectional nature and modest variance explained by current models, future prospective longitudinal studies incorporating direct respiratory muscle testing, comprehensive body composition metrics, and larger multi-center cohorts are needed to further validate the clinical utility of the muscle-lung axis.

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Conflict of Interest

MALDM is a current member of the Editorial Board of the SAAP Journal of Integrative Physiology. However, to ensure scientific objectivity, the author was completely blinded to the peer review process, editorial decisions, and final selection of the manuscript. No other financial, personal, or professional conflicts of interest exist regarding the publication of this research.

Disclosure of AI Use

The authors declare that no AI-assisted technologies or Large Language Models (LLMs) were used in the writing, editing, or preparation of the manuscript, nor were they used in the creation, generation, or modification of any of the tables or data presented herein.

Authors' Contributions

MALDM was responsible for conceptualization, study design,

recruitment, statistical modeling, and original drafting. SG was responsible for supervision, institutional coordination, discussion refinement, and manuscript editing. DDKA contributed to clinical assessments, dynamometry and spirometry data acquisition, and database curation. SPM contributed to literature search, GLI-2012 equation validation, biochemical mechanism review, and draft reviewing. PWDW was responsible for methodological validation, SPSS statistical analysis, and data tabulation. All authors approved the final version of the manuscript.

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