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ORIGINAL RESEARCH

Tracking Real-World Physical Activity in Chronic Obstructive Pulmonary Disease Over One Year: Results from a Monocentric, Prospective, Observational Cohort Study

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Introduction: Lung function constraints and comorbidities such as coronary heart disease, sarcopenia, and mood disorders make chronic obstructive pulmonary disease (COPD) patients avoid physical activity (PA). However, PA represents an important pillar of COPD management and is explicitly recommended by professional associations to enhance physical functioning and positively modulate disease progression.

Methods: In this monocentric, prospective, observational feasibility study, it was our primary objective to investigate the association between PA and the evolution of the COPD assessment test (CAT) and the occurrence of acute exacerbations of COPD (AECOPD), respectively. To this end, we equipped 42 COPD patients with an activity tracking wearable and telemonitored their daily PA levels over one year using a dedicated web-based interface. Patients additionally provided weekly CAT scores using the same telehealth platform and came in for 3 study visits to assess functional parameters and biochemical markers related to nutrition and inflammation.

Results: A principal study finding was that PA was inversely associated with CAT score (drop of 0.21 points associated with an increase of 1000 daily steps, $p = 0.004$), and that the 50% of patients with higher PA levels showed less CAT score progression over time (0.42 points per year) than the 50% of patients with lower PA levels (3.26 points per year) ($p < 0.001$). In addition, higher PA levels were significantly associated with a lower likelihood of experiencing a moderate-to-severe AECOPD (31% risk reduction associated with an increase of 1000 daily steps, $p = 0.0097$).

Discussion: Our study demonstrates the relevance of PA for key COPD outcome metrics in a real-world setting and underpins the importance of PA for COPD self-management in everyday life. Our study paves the way for future intervention trials to prospectively identify medically relevant PA thresholds and establish training recommendations for different patient subgroups.

Keywords: CAT score, COPD, physical activity, telemonitoring, wearable device

Introduction

Both the Global Initiative for Chronic Obstructive Lung Disease (GOLD)[1] and the European Respiratory Society (ERS)[2] advocate a comprehensive approach to chronic obstructive pulmonary disease (COPD) management, including complementation of medical treatment with non-pharmacological interventions. Physical activity (PA) represents an important pillar of COPD self-management with undisputed evidence for benefit at various levels (including enhanced physical functioning, prevention of sarcopenia, and improved quality-of-life (QoL)). However, lung function impairments, limitations in physical capacity, and comorbidities such as coronary heart disease and sarcopenia critically impact exercise tolerability, resulting in exertional dyspnea, which can lead to PA avoidance.[3,4] While this evasion reflex might be counterbalanced in short-term guided training programs (such as outpatient pulmonary rehabilitation and

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telerehabilitation), it poses a major challenge for long-term training adherence and PA in everyday life.[2,5] In addition, training progress in COPD patients may not be as tangible as in healthy individuals, which may jeopardize motivation.

Wearable devices such as activity trackers are powerful tools to quantify PA levels in everyday life. Such devices have gained increasing attention in COPD and support the collection of real-world data on physical functioning.[6] Moreover, activity trackers may help to increase PA levels by providing motivational feedback through goal setting and monitoring.[7] Indeed, a recent meta-analysis showed that the use of wearable technology increases both the daily step count and 6-minute walking distance in COPD patients, even though the effects are short-lived.[6] As pulmonary rehabilitation represents a cornerstone of COPD management mainly based on exercise training, the rational combination of wearable technology and pulmonary rehabilitation may additionally boost PA levels in COPD patients.[6] It is also important to demarcate the different potential benefits of PA monitoring in COPD patients, including motivational support to remain active, goal setting, other perceived physical or mental health benefits, and general interest in PA tracking.[8]

We here report the findings of a prospective, observational feasibility study of PA telemonitoring in COPD. Major research questions addressed include the association of real-world PA on the evolution of the COPD assessment test (CAT) score[9] as well as on acute exacerbations of COPD (AECOPD).

Materials and Methods

Study Design and Eligibility Criteria

This monocentric, prospective, observational, exploratory feasibility study was conducted at the Lung Center of the Cantonal Hospital St. Gallen, a tertiary care hospital in Eastern Switzerland. Patients were eligible for study inclusion if they had a confirmed diagnosis of COPD GOLD risk group B or E and if they were able and willing to provide written informed consent (inclusion criteria). In contrast, patients were not eligible for study participation if they were unable to follow the trial procedures for any reason, including insufficient knowledge of the trial language (exclusion criterion). Dropouts were not replaced, but data collected until dropout were used for analysis. Data reporting has been performed following the STROBE guidelines for cohort studies (www.strobe-statement.org), with some intellectual freedom retained.

Remote Monitoring of PA and CAT Score Evolution

To longitudinally track real-world PA, study participants were equipped with a commercial activity-tracking device recording step count (Garmin Vivofit® 3). Patients were trained to regularly synchronize their data to Garmin Connect™, the tracker's companion application installed on the patients' smartphones. We used "Evita" by Swisscom[10,11] for remote patient monitoring by study investigators. Using this platform, patients shared their daily PA levels by synchronizing their Garmin account and also provided weekly CAT scores as previously reported.[10,12] Using a web-based interface (web client), the study investigators could see the synchronized data in quasi real-time. PA data were continuously collected (ie, 24/7), while CAT scores were collected once a week (with patients being asked to fill out the questionnaire always on Mondays). This setup allowed us to longitudinally track PA (Supplemental Figure 1) and CAT scores (Supplemental Figure 2) over one year under real-world conditions.

Study Procedures

Enrolled patients remained in the study for one year and came in for 3 visits (baseline, 6 months, 12 months). On these occasions, PA levels and CAT scores were discussed, and technical support was provided as applicable. Moreover, further readouts were performed which were mainly targeted at physical composition and functioning as well as blood chemistry for nutrition-related and inflammatory markers. Specifically, we assessed lung function using spirometry (Vyntus™ SPIRO PC Spirometer), body composition using bioelectrical impedance analysis (BIA) (Akern BIA 101 Anniversary ASE), and measured handgrip strength (HGS) using dynamometry (CAMRY Digital Hand Dynamometer). Procedures for the assessments were performed in strict accordance with the manufacturer's instructions. Blood markers assessed included total protein, albumin, 25-OH vitamin D3 and C-reactive protein (CRP). During the study visits, patients also filled out

a standardized nutritional risk screening questionnaire (NRS 2002)[13] to identify potential malnutrition. Data on the severity and time of AECOPD were extracted from the patients' electronic health records. In all cases, AECOPD were clinically documented by the treating physician and classified into mild/moderate/severe according to relevant guidelines.

Data Analysis and Statistics

A sample size of 42 patients was considered for the current study. Statistical simulations showed that this sample size was sufficient to detect a significant association between PA and the CAT score, with a power of >90% and a two-sided significance level of 0.05. The study's primary objective was to investigate the association of PA with COPD-specific outcome metrics (CAT score and AECOPD). The study's secondary objectives were to investigate the association of PA with further parameters, including HGS, body composition, and blood-based markers related to nutrition and inflammation.

The evolution of PA over time as well as the association between PA and CAT score and other variables were analyzed using linear mixed models. The slope estimates and the associated 95% confidence intervals (CI) and p-values are reported. The association between the evolution of PA (daily step counts) and the occurrence of moderate-to-severe AECOPD was evaluated using the Andersen–Gill formulation of the Cox proportional hazards model, which is appropriate for the analysis of recurrent time-to-event data with time-varying predictors.[14] More specifically, the Andersen-Gill model is a simple extension of the common Cox proportional hazards model incorporating a counting process formulation. The recurrent events correspond to the occurrences of moderate-to-severe AECOPD and the time-dependent covariate corresponds to the daily PA. The input data consists of observations (rows of the data) including the covariate (daily PA), a status indicator (1 = AECOPD event; 0 = censored) along with a time interval (start-stop) over which this information applies. Data analyses were performed using the R statistical software (r-project.org) including the extension package survival. The nominal significance level was set to 0.05.

Results

Tracking Real-World PA is Feasible in COPD

Real-world data on PA are a valuable resource for remote patient monitoring and assessment of physical functioning in everyday life. Here, we monitored PA levels (daily step count) of COPD patients over one year using unobtrusive wearables. We recruited 42 patients with COPD GOLD risk group B or E (coded as PA001-PA042) for the study. Over the course of the study, 7 dropouts (17%) were documented. The patients' self-reported reasons for dropout were overwhelming effort associated with study participation in three patients (43%), technical complexity/overburdening in two patients (29%), allergic skin reaction to the activity tracker in one patient (14%), and the feeling of being traced and watched in one patient (14%). Patient characteristics at baseline are provided in Table 1.

Real-world PA tracking could be successfully established in all patients such that reasonable PA signals could be captured. Data completeness, ie, the fraction of days for which PA recordings were available, was roughly 75% (Supplemental Figure 1). Reasons for incomplete data included non-adherence, hospitalization, technical issues, early battery exhaustion, and missing data synchronization with Garmin Connect™ (leading to data loss/overwriting when the local memory capacity was used up). The median number of daily steps was 4467, with individual patients exhibiting much lower or higher values (range 932–12,128) (Supplemental Figure 1). PA levels were positively associated with baseline FEV1 ($p = 0.013$) and baseline FEV1/FVC ($p = 0.0322$) but were independent from other factors at baseline, including FVC, body mass index (BMI), age, and sex ($p > 0.05$, data not shown).

Taken together, long-term PA activity tracking of COPD patients by unobtrusive wearables is feasible and generates real-world data depicting individual PA trajectories.

PA Correlates Inversely with CAT Score Changes Over Time

We found a significant inverse correlation of PA levels with CAT score, with an increase of 1000 daily steps being associated with a drop of 0.21 points (95% CI: 0.06 to 0.37) in CAT score ($p = 0.004$, Figure 1A). We further stratified the cohort into PA^{high} vs PA^{low} patients according to 50^{th} percentile statistics and looked at the evolution of the CAT score

Table 1 Patient Characteristics at Baseline (n = 42)

Median Age, Years (Range)	**66 (46–83)**
Sex distribution, % of patients (n)	
Female	50 (21)
Male	50 (21)
Median BMI, kg/m^2 (range)	26 (17–43)
Smoking status, % of patients (n)	
Never	5 (2)
Former	81 (34)
Current	14 (6)
GOLD risk class, % of patients (n)	
B	55 (23)
E	45 (19)
GOLD stage, % of patients (n)	
1	2 (1)
2	48 (20)
3	36 (15)
4	14 (6)
Median FEV1, % predicted (range)	47 (22–106)
Pharmacological treatment for COPD, % of patients (n)	
SAMA	7 (3)
SABA	38 (16)
LAMA	90 (38)
LABA	93 (39)
ICS	31 (13)
Methylxanthines	0 (0)
Systemic corticosteroids	14 (6)
Mucolytics	10 (4)
Non-invasive home ventilation, % of patients (n)	5 (2)
Median Charlson comorbidity index (range)	1 (0–6)
Comorbidities, % of patients (n)	57 (24)
Obesity	31 (13)
Arterial hypertension	38 (16)
Coronary artery disease	19 (8)
Congestive heart failure	2 (1)
History of myocardial infarction	10 (4)
Pulmonary hypertension	7 (3)
History of malignancy	12 (5)
Diabetes mellitus	7 (3)
Renal failure	10 (4)
Depression	14 (6)
Sleep apnea	29 (12)

Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease; FEV1, forced expiratory volume in one second; GOLD, Global Initiative for Chronic Obstructive Lung Disease; ICS, inhaled corticosteroids; LABA, long-acting beta agonist; LAMA, long-acting muscarinic antagonist; SABA, short-acting beta agonist; SAMA, short-acting muscarinic antagonist.

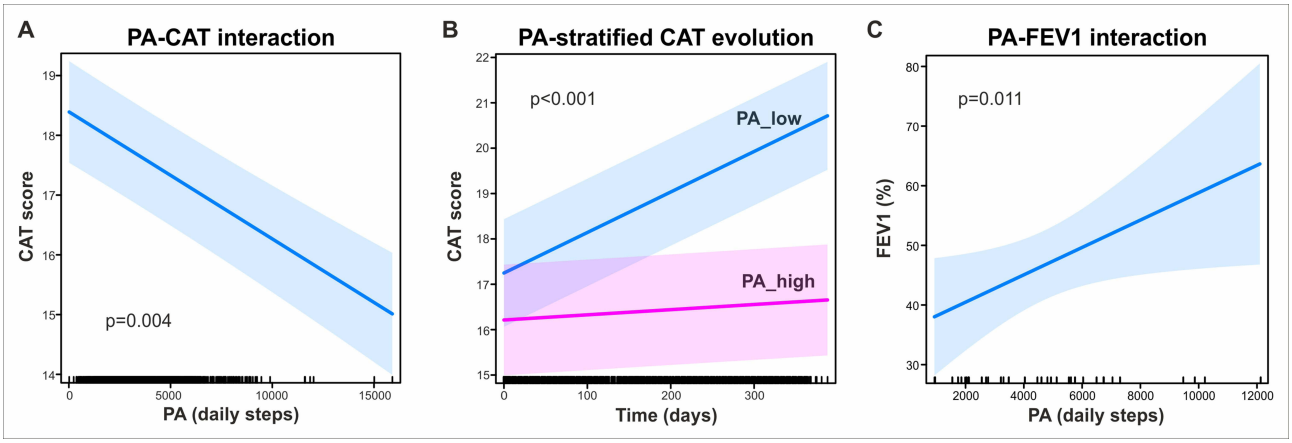

Figure 1 Association of PA levels with CAT score and FEV1. (**A**) PA levels are inversely correlated with CAT score. (**B**) Patients with more PA (50th percentile) show less CAT score progression over time. (**C**) PA levels are positively correlated with FEV1.
Abbreviations: CAT, COPD assessment test; COPD, chronic obstructive pulmonary disease; FEV1, forced expiratory volume in one second; PA, physical activity.

over the study duration of one year. PA^{low} patients had a CAT score evolution of 3.26 points per year (95% CI: 2.76 to 3.76) which was significantly worse than PA^{high} patients who had a CAT score increase of 0.42 points per year (95% CI: −0.07 to 0.90, $p < 0.0001$, Figure 1B). PA was positively correlated to FEV1 ($p = 0.011$, Figure 1C), indicating that lung function constraints translate into reduced PA levels in everyday life.

No significant associations of PA were found for HGS, body composition (fat mass, fat-free mass, body cell mass, extracellular mass), and blood-borne markers (ie, total protein, albumin, 25-OH vitamin D3 and CRP) ($p > 0.05$, data not shown).

PA is Associated with Reduced AECOPD Risk

We next sought to investigate the significance of real-world PA for the risk of AECOPD. In exacerbating patients, we episodically observed highly concordant, inverse trajectories of PA and CAT scores towards a documented AECOPD (Figure 2A). While our study was not powered by individual AECOPD prediction based on characteristic PA declines preceding AECOPD, we investigated the hazard of suffering AECOPD dependent on the level of PA during study participation. A significant inverse association was found between PA levels and the incidence of moderate-to-severe AECOPD (hazard ratio associated with a daily 1000 steps increases = 0.69, 95% CI: 0.52–0.91, $p = 0.0097$) (Figure 2B and C). Conversely, a decrease of 1000 steps per day was associated with a 45% increase in the risk of moderate-to-severe AECOPD. Of note, the association between PA and the risk of moderate-to-severe AECOPD was independent of FEV1 at baseline. Thus, increased PA in everyday life is associated with a reduced risk of experiencing moderate-to-severe AECOPD.

Discussion

Although COPD is characterized by exertional dyspnea leading to PA avoidance, exercise training is explicitly recommended to maintain physical functioning, counteract muscle wasting, slow down disease progression, and prevent AECOPD. Digital technology, including wearable devices and web-based support,[6,15,16] may promote PA in COPD patients through goal setting and mindfulness. In addition, telerehabilitation has been shown to be equally effective as conventional outpatient pulmonary rehabilitation,[17] which further corroborates the use of digital technology for COPD management.

The current study demonstrates the feasibility of long-term monitoring of PA in COPD patients under real-world conditions using digital technology and its use in discovering important clinical associations, including CAT score and the occurrence of AECOPD. Our study shows high adherence to activity tracking as well as reasonable data completeness after one year (approximately 75%). Of note, missing digital literacy of elderly patients was initially identified as an important study risk, and patients were supported correspondingly, especially at study start but also during follow-up

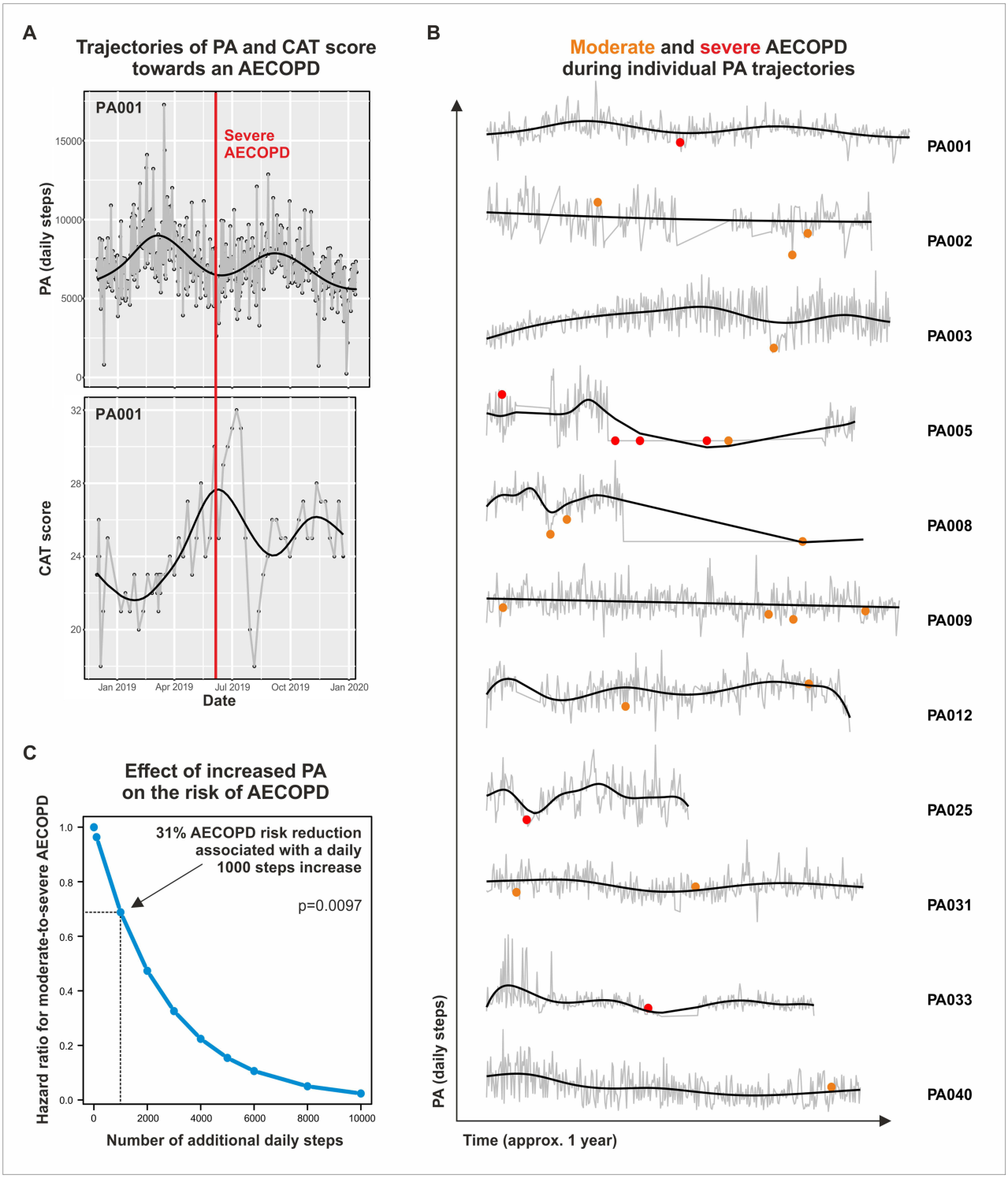

Figure 2 PA and risk of moderate-to-severe AECOPD. (**A**) Anti-parallel evolution of PA levels and CAT score in a severely exacerbating patient (PA001). (**B**) Overlay plots of PA trajectories of 11 patients (PA001, PA002, PA003, PA005, PA008, PA009, PA012, PA025, PA031, PA033, PA040) and documented moderate-to-severe AECOPD, color-coded according to severity. (**C**) Calculated effect size of moderate-to-severe AECOPD risk reduction by increased PA.
Abbreviations: AECOPD, acute exacerbation of COPD; CAT, COPD assessment test; COPD, chronic obstructive pulmonary disease; PA, physical activity.

visits and throughout. Generally, user-friendliness of digital health applications is of key importance, as a significant part of non-compliance with digital technology results from technical difficulties and complicated systems.[18]

Our study shows a high degree of inter-patient variation in PA that is only partially explainable by COPD stages. Higher PA levels were associated with lower CAT scores and further correlated with a more favorable score evolution, suggesting that PA may positively modulate COPD progression. In addition, less physically active patients had a higher chance of suffering moderate-to-severe AECOPD requiring emergency medication or hospitalization independent of baseline FEV1.

Some limitations are applicable to our study that may prohibit generalized conclusions. First, case numbers were limited, and the study was neither controlled nor interventional. Second, the study population was heterogeneous and included different COPD stages. Third, the observation period for some patients coincided with national COVID-19 lockdowns in Switzerland,[19,20] which may have impacted their PA level (however, no statistically significant effects were detectable – possibly due to high variation of PA levels and low case numbers). Fourth, considering the real-world setting of the study, there were no ultimate means to ensure that the activity trackers were worn continuously by the patients without notable interruptions.

Our study adds to the emerging body of evidence on the use of digital technology in non-pharmacological COPD management in various settings. As an example, using a corresponding smartphone application supports PA maintenance after pulmonary rehabilitation for COPD.[21] Furthermore, the use of a pedometer during a 3-months individualized training program promoted higher improvements in PA levels in a randomized controlled trial.[22] Our study complements and extends such short-term data by offering a real-world look on PA and CAT evolution over a prolonged period of time. Coupling long-term PA monitoring to a specific intervention holds great potential for PA promotion in a real-world setting and warrants further investigation.

Potentially, the approach taken here is also translatable to other (chronic) respiratory diseases for which exercise training represents an important therapeutic pillar, including lung fibrosis, pulmonary hypertension, and post-infection syndromes. In these entities, the architecture of PA monitoring and the complementary ground truth readouts should be adapted accordingly, taking into account disease-specific characteristics. Ultimately, wearable technology and PA monitoring may improve clinical outcomes and QoL also in these settings.

Taken altogether, our study corroborates the importance of PA for COPD self-management and sets the stage for future randomized, controlled trials to determine effect sizes and establish specific training recommendations for this patient cohort. Although passive PA monitoring represents a mindfulness-based intervention, provision of motivational feedback may further promote PA in vulnerable patients. Our overarching conclusions are that (i) remote PA tracking over one year is feasible in COPD patients, that (ii) real-world PA levels are associated with CAT score progression over time, that (iii) real-world PA levels are associated with AECOPD risk over time, and that (iv) real-world PA data may identify frequent exacerbators or even have the potential to predict AECOPD.

Abbreviations

AECOPD, acute exacerbation of COPD; BIA, bioelectrical impedance analysis; BMI, body mass index; CAT, COPD assessment test; COPD, Chronic obstructive pulmonary disease; CPAP, Continuous positive airway pressure; CRP, C-reactive protein; FEV1, forced expiratory volume in one second; FVC, Forced vital capacity; GOLD, Global Initiative for Chronic Obstructive Lung Disease; HGS, Handgrip strength; ICS, Inhaled corticosteroids; LABA, Long-acting beta agonist; LAMA, Long-acting muscarinic antagonist; PA, Physical activity; QoL, Quality-of-life; SABA, Short-acting beta agonist; SAMA, Short-acting muscarinic antagonist.

Data Sharing Statement

Data underlying this manuscript are available from Dr. Florent Baty (florent.baty@kssg.ch) upon reasonable request.

Ethics Statement

The study was approved by the Ethikkommission Ostschweiz (BASEC 2018-00906) and registered with clinicaltrials.gov (NCT03855670). The study complies with the Declaration of Helsinki.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors have no conflicts of interest to declare in this work. No medical writer or generative AI tool was involved in the preparation of the manuscript.

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