

# World Journal of *Clinical Cases*

*World J Clin Cases* 2022 January 7; 10(1): 1-396



**MINIREVIEWS**

- 1 Omicron variant (B.1.1.529) of SARS-CoV-2: Mutation, infectivity, transmission, and vaccine resistance  
*Ren SY, Wang WB, Gao RD, Zhou AM*
- 12 Hepatitis B virus reactivation in rheumatoid arthritis  
*Wu YL, Ke J, Zhang BY, Zhao D*
- 23 Paradoxical role of interleukin-33/suppressor of tumorigenicity 2 in colorectal carcinogenesis: Progress and therapeutic potential  
*Huang F, Chen WY, Ma J, He XL, Wang JW*

**ORIGINAL ARTICLE****Case Control Study**

- 35 Changes in rheumatoid arthritis under ultrasound before and after sinomenine injection  
*Huang YM, Zhuang Y, Tan ZM*
- 43 Benefits of multidisciplinary collaborative care team-based nursing services in treating pressure injury wounds in cerebral infarction patients  
*Gu YH, Wang X, Sun SS*

**Retrospective Study**

- 51 Outcomes and complications of open, laparoscopic, and hybrid giant ventral hernia repair  
*Yang S, Wang MG, Nie YS, Zhao XF, Liu J*
- 62 Surgical resection of intradural extramedullary tumors in the atlantoaxial spine *via* a posterior approach  
*Meng DH, Wang JQ, Yang KX, Chen WY, Pan C, Jiang H*
- 71 Vancomycin lavage for the incidence of acute surgical site infection following primary total hip arthroplasty and total knee arthroplasty  
*Duan MY, Zhang HZ*
- 79 Distribution of transient receptor potential vanilloid-1 channels in gastrointestinal tract of patients with morbid obesity  
*Atas U, Erin N, Tazegul G, Elpek GO, Yildirim B*
- 91 Value of neutrophil-lymphocyte ratio in evaluating response to percutaneous catheter drainage in patients with acute pancreatitis  
*Gupta P, Das GC, Bansal A, Samanta J, Mandavdhare HS, Sharma V, Naseem S, Gupta V, Yadav TD, Dutta U, Varma N, Sandhu MS, Kochhar R*

- 104 Influence of overweight and obesity on the mortality of hospitalized patients with community-acquired pneumonia  
*Wang N, Liu BW, Ma CM, Yan Y, Su QW, Yin FZ*
- 117 Minimally invasive open reduction of greater tuberosity fractures by a modified suture bridge procedure  
*Kong LP, Yang JJ, Wang F, Liu FX, Yang YL*
- 128 Increased levels of lactate dehydrogenase and hypertension are associated with severe illness of COVID-19  
*Jin ZM, Shi JC, Zheng M, Chen QL, Zhou YY, Cheng F, Cai J, Jiang XG*
- 136 Age, alcohol, sex, and metabolic factors as risk factors for colonic diverticulosis  
*Yan Y, Wu JS, Pan S*
- 143 Evaluation of right-to-left shunt on contrast-enhanced transcranial Doppler in patent foramen ovale-related cryptogenic stroke: Research based on imaging  
*Xiao L, Yan YH, Ding YF, Liu M, Kong LJ, Hu CH, Hui PJ*
- 155 Characterization of focal hypermetabolic thyroid incidentaloma: An analysis with F-18 fluorodeoxyglucose positron emission tomography/computed tomography parameters  
*Lee H, Chung YS, Lee JH, Lee KY, Hwang KH*
- Clinical Trials Study**
- 166 Low-dose intralesional injection of 5-fluorouracil and triamcinolone reduces tissue resident memory T cells in chronic eczema  
*Wu Y, Wang GJ, He HQ, Qin HH, Shen WT, Yu Y, Zhang X, Zhou ML, Fei JB*
- Observational Study**
- 177 Alterations in blink and masseter reflex latencies in older adults with neurocognitive disorder and/or diabetes mellitus  
*Bricio-Barrios JA, Ríos-Bracamontes E, Ríos-Silva M, Huerta M, Serrano-Moreno W, Barrios-Navarro JE, Ortiz GG, Huerta-Trujillo M, Guzmán-Esquivel J, Trujillo X*
- 189 Predicting adolescent perfectionism: The role of socio-demographic traits, personal relationships, and media  
*Livazović G, Kuzmanović K*
- 205 Novel m.4268T>C mutation in the mitochondrial tRNA<sup>Leu</sup> gene is associated with hearing loss in two Chinese families  
*Zhao LJ, Zhang ZL, Fu Y*
- 217 Superior mesenteric venous thrombosis: Endovascular management and outcomes  
*Alnahhal K, Toskich BB, Nussbaum S, Li Z, Erben Y, Hakaim AG, Farres H*
- Randomized Controlled Trial**
- 227 Zinc carnosine-based modified bismuth quadruple therapy vs standard triple therapy for *Helicobacter pylori* eradication: A randomized controlled study  
*Ibrahim N, El Said H, Choukair A*

**CASE REPORT**

- 236** Acquired coagulation dysfunction resulting from vitamin K-dependent coagulation factor deficiency associated with rheumatoid arthritis: A case report  
*Huang YJ, Han L, Li J, Chen C*
- 242** Intraoperative thromboelastography-guided transfusion in a patient with factor XI deficiency: A case report  
*Guo WJ, Chen WY, Yu XR, Shen L, Huang YG*
- 249** Positron emission tomography and magnetic resonance imaging combined with computed tomography in tumor volume delineation: A case report  
*Zhou QP, Zhao YH, Gao L*
- 254** Successful response to camrelizumab in metastatic bladder cancer: A case report  
*Xie C, Yuan X, Chen SH, Liu ZY, Lu DL, Xu F, Chen ZQ, Zhong XM*
- 260** HER2 changes to positive after neoadjuvant chemotherapy in breast cancer: A case report and literature review  
*Wang L, Jiang Q, He MY, Shen P*
- 268** Hyper-accuracy three-dimensional reconstruction as a tool for better planning of retroperitoneal liposarcoma resection: A case report  
*Ye MS, Wu HK, Qin XZ, Luo F, Li Z*
- 275** Recurrent postmenopausal bleeding - just endometrial disease or ovarian sex cord-stromal tumor? A case report  
*Wang J, Yang Q, Zhang NN, Wang DD*
- 283** Complex proximal femoral fracture in a young patient followed up for 3 years: A case report  
*Li ZY, Cheng WD, Qi L, Yu SS, Jing JH*
- 289** Bilateral Hypertrophic Olivary Degeneration after Pontine Hemorrhage: A Case Report  
*Zheng B, Wang J, Huang XQ, Chen Z, Gu GF, Luo XJ*
- 296** Clinical characteristics and outcomes of primary intracranial alveolar soft-part sarcoma: A case report  
*Chen JY, Cen B, Hu F, Qiu Y, Xiao GM, Zhou JG, Zhang FC*
- 304** Removal of laparoscopic cerclage stitches *via* laparotomy and rivanol-induced labour: A case report and literature review  
*Na XN, Cai BS*
- 309** Cerebral venous sinus thrombosis in pregnancy: A case report  
*Zhou B, Huang SS, Huang C, Liu SY*
- 316** Eustachian tube teratoma: A case report  
*Li JY, Sun LX, Hu N, Song GS, Dou WQ, Gong RZ, Li CT*

- 323** Protein-losing enteropathy caused by a jejunal ulcer after an internal hernia in Petersen's space: A case report  
*Yasuda T, Sakurazawa N, Kuge K, Omori J, Arai H, Kakinuma D, Watanabe M, Suzuki H, Iwakiri K, Yoshida H*
- 331** Lunate dislocation with avulsed triquetral fracture: A case report  
*Li LY, Lin CJ, Ko CY*
- 338** Clinical manifestations and prenatal diagnosis of Ullrich congenital muscular dystrophy: A case report  
*Hu J, Chen YH, Fang X, Zhou Y, Chen F*
- 345** Diagnosis and guidance of treatment of breast cancer cutaneous metastases by multiple needle biopsy: A case report  
*Li ZH, Wang F, Zhang P, Xue P, Zhu SJ*
- 353** Test of incremental respiratory endurance as home-based, stand-alone therapy in chronic obstructive pulmonary disease: A case report  
*Dosbaba F, Hartman M, Batalik L, Brat K, Plutinsky M, Hnatiak J, Formiga MF, Cahalin LP*
- 361** Diagnostic and surgical challenges of progressive neck and upper back painless masses in Madelung's disease: A case report and review of literature  
*Yan YJ, Zhou SQ, Li CQ, Ruan Y*
- 371** Suspected cerebrovascular air embolism during endoscopic esophageal varices ligation under sedation with fatal outcome: A case report  
*Zhang CMJ, Wang X*
- 381** An atypical primary malignant melanoma arising from the cervical nerve root: A case report and review of literature  
*Shi YF, Chen YQ, Chen HF, Hu X*
- 388** Epidural blood patch for spontaneous intracranial hypotension with subdural hematoma: A case report and review of literature  
*Choi SH, Lee YY, Kim WJ*

**ABOUT COVER**

Editorial Board Member of *World Journal of Clinical Cases*, Ravi Kant, MD, Associate Professor, Division of Endocrinology, Diabetes and Metabolism, Medical University of South Carolina/Anmed Campus, Anderson, SC 29621, United States. rkant82@hotmail.com

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## Test of incremental respiratory endurance as home-based, stand-alone therapy in chronic obstructive pulmonary disease: A case report

Filip Dosebaba, Martin Hartman, Ladislav Batalik, Kristian Brat, Marek Plutinsky, Jakub Hnatiak, Magno F Formiga, Lawrence Patrick Cahalin

**ORCID number:** Filip Dosebaba 0000-0003-0707-2739; Martin Hartman 0000-0003-0378-1677; Ladislav Batalik 0000-0003-2147-1541; Kristian Brat 0000-0003-1674-228X; Marek Plutinsky 0000-0003-1723-3794; Jakub Hnatiak 0000-0002-3991-2512; Magno F Formiga 0000-0003-0327-9695; Lawrence Patrick Cahalin 0000-0001-8447-1026.

**Author contributions:** Dosebaba F, Hartman M, and Batalik L contributed to the conception of the research; Brat K and Plutinsky M conducted the data interpretation; Dosebaba F and Hnatiak J drafted the manuscript; Formiga MF, Cahalin LP, and Dosebaba F revised and edited the manuscript for content; All authors read and approved the final version of the manuscript.

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**Filip Dosebaba, Martin Hartman, Ladislav Batalik, Jakub Hnatiak,** Department of Rehabilitation, University Hospital Brno, Brno 62500, Czech Republic

**Ladislav Batalik,** Department of Public Health, Faculty of Medicine, Masaryk University Brno, Brno 62500, Czech Republic

**Kristian Brat, Marek Plutinsky,** Department of Respiratory Diseases, University Hospital Brno, Brno 62500, Czech Republic

**Kristian Brat,** International Clinical Research Center, St. Anne's University Hospital, Brno 65691, Czech Republic

**Magno F Formiga,** Departamento de Fisioterapia, Universidade Estadual da Paraíba, Campina Grande 58051, Brazil

**Lawrence Patrick Cahalin,** Department of Physical Therapy, University of Miami – Miller School of Medicine, Coral Gables, FL 33101, United States

**Corresponding author:** Ladislav Batalik, MSc, PhD, Physiotherapist, Research Scientist, Department of Rehabilitation, University Hospital Brno, Jihlavská 20, Brno 62500, Czech Republic. [batalik.ladislav@fnbrno.cz](mailto:batalik.ladislav@fnbrno.cz)

### Abstract

#### BACKGROUND

The prevalence of chronic obstructive pulmonary disease (COPD) is increasing worldwide, and at the same time it is associated with increased mortality and reduced quality of life. Efforts to build sustainable rehabilitation approaches to COPD treatment and prevention are crucial. The system of long-term pulmonary rehabilitation care is insufficient. The main reasons for the absence of these outpatient programs are the lack of experience, the lack of interest of insurance companies in secondary prevention programs, and the lack of healthcare facilities in large geographical areas. The possibility of at-home pulmonary rehabilitation models (telemonitoring and telecoaching) could solve this problem.

#### CASE SUMMARY

A 71-year-old man with severe COPD, Global Initiative for Obstructive Lung

Checklist (2016), and the manuscript was prepared and revised according to the CARE Checklist (2016).

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Diseases stage 3 underwent an 8-wk remotely monitored inspiratory muscle training with a device based on the test of incremental respiratory endurance method. Spirometry, body plethysmography, test of incremental respiratory endurance examination, 6-min walking test, body mass index, airflow obstruction, dyspnea, exercise capacity index, and subjective perception of dyspnea were performed as part of the initial and final examination. The patient performed training at home, and the physiotherapist monitored the patient remotely through a web application that allowed the physiotherapist to evaluate all training parameters in real-time and respond to any problems. After 8 wk of home training, there was a significant increase in all monitored values: maximal inspiratory pressure, a novel parameter sustained maximal inspiratory pressure, forced expiratory volume in 1 s, total lung capacity, forced vital capacity, peak expiratory flow, and inspiratory capacity. There was also an improvement in the perception of dyspnea according to the COPD Assessment Test and a modified Medical Research Council Breathlessness Scale, an increase in exercise tolerance according to the 6-min walking test, and a decrease in the exercise capacity index as a predictor of prognosis.

**CONCLUSION**

Respiratory telerehabilitation was greatly beneficial in a cooperative patient with COPD and may represent an alternative therapeutic approach to the increasing incidence of all lung diseases.

**Key Words:** Chronic obstructive pulmonary disease; Test of incremental respiratory endurance; Inspiratory muscle training; Telerehabilitation; Case report

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**Core Tip:** Inspiratory muscle training with a telerehabilitation device motivated a patient to participate actively and be more responsible for his health. The test of incremental respiratory endurance allows remote monitoring of the patient's inspiratory muscle training in real-time, while the training goal is automatically adjusted based on a patient's inspiratory performance and status before the start of each inspiratory muscle training session. Also, the novel sustained maximal inspiratory pressure may be a more sensitive predictor of chronic obstructive pulmonary disease severity than the current commonly used maximal inspiratory pressure.

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**INTRODUCTION**

The prevalence of chronic obstructive pulmonary disease (COPD) has increased worldwide and is associated with increased mortality and reduced quality of life[1]. In the Czech Republic, the estimated prevalence is about 800000 patients (7%-8%) affected by COPD[2]. Therefore, pulmonary rehabilitation should be an integral part of the comprehensive treatment of patients with COPD. However, there is still no effective system of lifelong pulmonary rehabilitation in the Czech Republic or abroad. Thus, there is a large discrepancy between the theoretical need and these programs actual existence and availability[1,3]. The solution to this problem could be the possibility of domestic models of pulmonary rehabilitation. In 2015, the American Thoracic Society and the European Respiratory Society published a political statement committing themselves to promote and expand home pulmonary rehabilitation that is evidence-based and accessible to most COPD patients[4]. Based on the results of meta-analyses, it is proven that technologies developed for telerehabilitation are essential

because they improve mouth pressures, lung function, and quality of life[5,6]. New technologies have expanded potential opportunities for pulmonary rehabilitation, increasing the efficiency of home training and removing barriers through telemonitoring, telecoaching, and virtual reality[7,8]. This clinical case aims to report on a patient with COPD who performed inspiratory muscle training (IMT) with the PrO2® device (Design Net, Smithfield, United States), which enabled remote monitoring and evaluation of IMT in real-time using a cloud-based online platform. This case report demonstrates the substantial benefits of respiratory telerehabilitation in an epidemiologically serious disease such as COPD.

Additionally, patients see the real-time achievement of their goals during PrO2 IMT, which had a very motivating effect and likely improved his adherence to respiratory telerehabilitation. The PrO2 automatically adjusts the IMT program based on a patient's inspiratory performance and status before the start of each IMT session, decreasing the need to physically visit the patient or the patient to visit the physiotherapist. Furthermore, IMT parameters (*i.e.* workload, number of breaths) can be adjusted remotely *via* the PrO2 app, making such IMT extremely useful clinically. We report on the substantial benefits of an innovative IMT program using the test of incremental respiratory endurance (TIRE) with the PrO2 device *via* telemonitoring.

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## CASE PRESENTATION

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### **Chief complaints**

A 71-year-old man with severe COPD with rapidly progressing dyspnea, low exercise tolerance, and hypoxemia.

### **History of present illness**

The patient was diagnosed with COPD in 2010. Over the last 5 years, the patient experienced a gradual progression of dyspnea that limited his performance of everyday activities.

### **History of past illness**

In 2019, the patient underwent Bentall's heart surgery with resection of the left atrial appendage. The patient did not claim any diseases of affluence.

### **Personal and family history**

The patient has a 30 pack-year history (20 cigarettes a day for 30 years) and has not smoked since 2008. He works as a managing director and denies any risk factors for lung disease from his occupation. His father contracted tuberculosis after the Second World War and died of lung cancer, and his brother has diabetes mellitus.

### **Physical examination**

The patient was afebrile with alveolar respiration and sinus rhythm, and his lower limbs were without swelling.

### **Laboratory examinations**

Alpha1-antitrypsin levels were normal. Arterial blood gas examination showed an oxygen partial pressure  $pO_2 = 7.67$  kPa; carbon dioxide partial pressure  $pCO_2 = 4.56$  kPa;  $pH = 7.46$ ; and blood saturation  $SpO_2 = 90\%$ .

### **Imaging examinations**

Computed tomography results demonstrated centrilobular emphysema bilaterally reflecting a severe obstructive ventilation disorder.

### **Further diagnostic work-up**

The patient underwent spirometry and body plethysmography examinations with the following results: forced expiratory volume in 1 s = 1.07 L; forced vital capacity = 1.94 L; inspiratory capacity = 1.57 L; total lung capacity (TLC) = 5.51 L; peak expiratory flow = 3.38 L. Inspiratory muscle performance was examined with the PrO2 device (Design Net, Smithfield, United States), showing the following results: maximal inspiratory pressure (MIP) = 57 cmH<sub>2</sub>O; sustained maximal inspiratory pressure (SMIP) = 404 PTU (pressure-time unit); inspiratory duration (ID) = 7.7s; and fatigue index test (FIT) = 12.1. Questionnaires assessed the subjective perception of dyspnea with a COPD Assessment Test score of 15 and modified Medical Research Council

Breathlessness score of 3. The six-minute walk test (6-MWT) was used to assess exercise tolerance, with the distance walked being 270 m, and the oxygen saturation decreased from 95% at baseline to 75% during the test. The multifactorial body mass index, airflow obstruction, dyspnea, and exercise (BODE) index was used as a predictor of prognosis with an initial score of 5. The Charlson Comorbidity Index calculated the 10-year mortality risk to be 53%.

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## FINAL DIAGNOSIS

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Severe COPD [Global Initiative for Obstructive Lung Diseases (GOLD) stage 3] with rapid progression of exercise intolerance.

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## TREATMENT

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The patient underwent an 8-wk, remotely monitored IMT program with a PrO2 device (Design Net, Smithfield, United States) at the University Hospital Brno between May and June 2021. The PrO2 device is protected by the United States Patent Application Publication No.: US 2017/0020439 A1. The Ethics Committee approved the project of the University Hospital Brno (01-020420/EK), and the patient also signed informed consent. After the previously described initial examinations, the patient was educated on using the PrO2 device, which was provided to use at home during the study period. Furthermore, the patient was educated about the IMT schedule and how to operate the device, and he received a training diary in which he regularly recorded notes of individual IMT sessions, including the rating of subjective workload using the Rating of Perceived Exertion as well as any subjective difficulties or technical problems.

### **Training description**

The PrO2 device must first be connected *via* bluetooth to a tablet that the patient also received as part of the study. The PrO2 app must be downloaded to the tablet, which then serves as a monitor for the PrO2 device so that IMT can be viewed by the patient and remotely. The app automatically prompts the user to perform a maximal inspiratory maneuver from residual volume to total lung capacity, which was always performed three times with the greatest inspiratory effort used for IMT by providing a template at a specific percentage of the MIP and SMIP that the patient used for visual biofeedback during all IMT sessions. The PrO2 app was used to set the patient's workload at 50% of the MIP and SMIP from the greatest inspiratory maneuver obtained before each IMT session, which was repeated for each IMT session of the study period, thus providing a new and up-to-date MIP and SMIP IMT template for each IMT session. The workload, therefore, was automatically adapted to the patient's actual condition and level of inspiratory muscle performance, thereby ensuring a safe and high rate of IMT progress, which is not possible with other IMT devices. The patient's goal during all IMT sessions was to inspire throughout at least 90% of the IMT area under the curve template, which if successful allowed the patient to progress to the next breath. However, if less than 90% of the IMT area under the curve template is achieved during IMT, the patient is prompted to inspire again with greater force to achieve 90% of the template. If the patient was unable to achieve 90% of the IMT template after three attempts, the IMT session was terminated to prevent excess fatigue and terminate ineffective IMT. The graphically and numerically evaluated MIP and SMIP template provides motivational biofeedback for the individual to continue improving his/her inspiratory efforts. The total number of breaths achieved during an IMT session and the MIP and SMIP template achieved with each inspiration were summed, providing an accumulated SMIP, which provided another key measurement of endurance from TIRE PrO2 IMT and associated app. A complete TIRE workout workload consists of 36 breaths, and the sum of the total area under the curve of all 36 breaths is provided, yielding endurance and inspiratory work achieved during each IMT session. After each IMT session, all IMT results described above were automatically transferred from a mobile phone or tablet housing the app to the appropriate account created on the website: [www.pro2fit.com](http://www.pro2fit.com). These results were remotely and individually assessed by a physiotherapist who provided feedback (telemonitoring) to the patient, including patient motivation as well as reasons for not achieving the current daily goal (telecoaching), among other IMT issues.

The standard TIRE IMT session consists of six levels (A-F), with each level consisting of 6 breaths yielding 36 breaths. There is a fixed rest period between breaths at each level, which gradually decreases from 60 s (level A) to 10 s (level F). This is a clinically proven training protocol preset in the PrO2 device but can be changed *via* the app. The training frequency for the case subject was 4 times a week for 8 wk[9].

## OUTCOME AND FOLLOW-UP

After 8 wk of IMT with the PrO2 device (adherence to IMT was 93%) (Table 1), the same examinations and tests performed at baseline were performed again, with the following results: forced expiratory volume in 1 s = 1.18; forced vital capacity = 2.12 L; inspiratory capacity = 1.95 L; TLC = 6.47 L; peak expiratory flow = 3.88 L; pO<sub>2</sub> = 6.81 kPa; pCO<sub>2</sub> = 5.39 kPa; pH = 7.42; SpO<sub>2</sub> = 89%; MIP = 107 cmH<sub>2</sub>O; SMIP = 524P TU; ID = 15 s; FIT = 21.8; COPD Assessment Test = 4, Medical Research Council Breathlessness = 2. During 6-MWT, the patient's performance improved to 330 m, and the decrease in oxygen saturation was substantially smaller (from 94% to 88%). The BODE index decreased to 4 (Table 2).

## DISCUSSION

Patients with COPD suffer from reduced exercise tolerance and weakness of the inspiratory muscles, which is objectively represented by a significant reduction in the MIP, representing the maximum pressure obtained during inspiration from residual volume. The clinical and diagnostic significance of MIP is undisputable. However, it provides a rather limited view of inspiratory muscle performance and does not reflect the generation of pressure from residual volume to TLC[9]. Measurement of MIP, SMIP, and ID from the TIRE and PrO2 device has excellent rest-retest reliability and proven validity in known groups with COPD[10]. The advantage of TIRE examination and IMT is the evaluation and training of strength, endurance, power, and work aimed at the inspiratory muscles and providing several key parameters, including MIP, SMIP, ID, and FIT[10]. Thus, TIRE IMT may become a more effective way of IMT than currently established methods to employ IMT because of the muscular strength component reflected by MIP, the muscular endurance component represented by ID, and the power/work component reflected by the SMIP and the need to achieve at least 90% of SMIP area under the curve to progress to the next breath[9]. It is important to note that ID is not the standard length of inspiration but rather the inspiratory flow during maximal inspiratory efforts through a 2 mm orifice in the mouthpiece of the PrO2 device with isokinetic-like resistance from residual volume to TLC[10].

One key factor of TIRE PrO2 testing and training includes the SMIP, which represents single-breath inspiratory endurance and work capacity and is presented as the area under the pressure/time curve with the unit of measure being pressure time unit (PTU) and joule (J). The slope of the SMIP curve is also essential since too steep of slope represents a rapid decrease in inspiratory muscle strength, short ID, and poor SMIP. Thus, TIRE PrO2 evaluation and training provide a comprehensive assessment of inspiratory muscle performance and changes from IMT, which are provided graphically and numerically in the tablet app during all inspiratory efforts, enabling the patient to generate more excellent results of inspiratory maneuvers and pressures to achieve greater IMT efforts[9,10].

Our patient's spirometry and body plethysmography values (forced expiratory volume in 1 s, forced vital capacity, inspiratory capacity, peak expiratory flow, TLC) also objectively improved, which is supported by other studies of IMT using other types of inspiratory training aids[11]. The increase in our case subject's MIP, SMIP, and ID is significant since McCreery *et al*[12] showed a significant correlation between pulmonary function and inspiratory muscle performance examined *via* the TIRE MIP, SMIP, and ID. It is also worth noting the substantial improvement in our patient's ID (almost 2 x more significant). A greater ID with more excellent airflow correlates with greater inspiratory muscle strength and the ability of the inspiratory muscles to generate more significant pressure for a longer period[9], which was associated with the substantial increase in MIP and SMIP in our case. The potential for further improvement of SMIP in our patient with COPD GOLD stage 3 will be limited after reaching a certain value because there appears to be a direct correlation between SMIP and the GOLD classification, and the SMIP of our patient is within the observed range for each GOLD classification group[9,10]. The increase in all TIRE parameters and thus

**Table 1 Training program and results**

Training date	Total power, PTU	Max MIP, cmH <sub>2</sub> O	Max FIT	Max power, PTU	Max time, s
01.07.2021 15:30	12.42	97	15	385	15
29.06.2021 16:03	13.52	109	17	393	17
27.06.2021 15:31	10.78	86	16	337	19
25.06.2021 11:02	11.51	80	17	355	17
23.06.2021 15:59	12.65	82	19	392	17
21.06.2021 18:07	12.92	93	18	399	17
19.06.2021 12:51	16.84	77	20	396	19
17.06.2021 16:30	13.73	85	21	455	18
15.06.2021 18:12	11.95	80	22	426	18
13.06.2021 17:18	11.14	72	15	362	15
11.06.2021 14:55	13.12	77	22	412	19
09.06.2021 14:37	13.30	72	21	434	15
07.06.2021 16:36	12.75	76	23	426	16
05.06.2021 12:37	12.34	82	20	412	16
03.06.2021	No training - health indisposition				
01.06.2021 15:38	12.97	75	20	441	16
30.05.2021 13:31	12.18	70	21	424	15
28.05.2021 14:57	11.40	76	17	390	14
27.05.2021 17:19	9.46	65	19	429	14
25.05.2021 15:35	12.98	61	26	439	20
23.05.2021 13:48	11.22	60	19	425	16
21.05.2021	No training - health indisposition				
19.05.2021 17:21	10.29	54	15	328	14
17.05.2021 12:41	12.73	65	20	416	15
15.05.2021 15:31	14.32	53	14	339	11
13.05.2021 15:12	12.69	53	26	421	17
11.05.2021 11:13	13.53	55	32	457	17
09.05.2021 13:38	12.69	75	27	454	16
07.05.2021 11:37	11.40	78	15	434	15

PTU: Pressure time unit; MIP: Maximal inspiratory pressure; FIT: Fatigue index test.

an improvement in inspiratory muscle performance appears to have had a positive effect on the increase in the 6-MWT distance ambulated. A greater 6-MWT distance is associated with a better prognosis regarding fewer hospital readmissions and lower mortality risk in patients with COPD[13].

The substantial increase in FIT in our case subject was likely due to the intensive IMT program, which elicited greater inspiratory muscle strength, endurance, power, and work. According to Wüthrich *et al*[14], a higher FIT score appears to be associated with less propensity to inspiratory muscle fatigue.

It is important to note that SMIP correlates positively with the BODE index, and an improvement in SMIP through IMT may potentially yield longer survival in patients with COPD[15,16]. Our results reflect this possibility, with the BODE index decreasing from 5 to 4 after only 8 wk of IMT.

Surprisingly, despite all of the above improvements, the patient’s final arterial blood gas examination revealed a modest decrease in pO<sub>2</sub> and a slight increase in pCO<sub>2</sub>. However, the patient did not report any adverse symptoms during the final testing,

Table 2 Changes of parameters before and after the test of incremental respiratory endurance

Parameters	Before TIRE	After TIRE
MIP, cmH <sub>2</sub> O	57	107
SMIP-POWER, PTU	404	524
FIT	12.1	21.8
ID, s	7.7	15.0
FEV1, L	1.07	1.18
FVC, L	1.94	2.12
IC, L	1.57	1.95
TLC, L	5.51	6.47
PEF, L	3.38	3.88
mMRC	3	2

TIRE: Test of incremental respiratory endurance; MIP: Maximal inspiratory pressure; SMIP: Sustained maximal inspiratory pressure; PTU: Pressure time unit; FIT: Fatigue index test; ID: Inspiratory duration; FEV1: Forced expiratory volume in 1 second; FVC: Forced vital capacity; IC: Inspiratory capacity; TLC: Total lung capacity; PEF: Peak expiratory flow; mMRC: Modified Medical Research Council Breathlessness.

and the Tension Time Index parameter, which detects the risk of respiratory failure, was standard. In contrast, after 8 wk of IMT, there was a significant improvement in the subjective perception of dyspnea according to the Medical Research Council Breathlessness (3 to 2) and COPD Assessment Test (15 to 4) questionnaires. In view of these findings, further research is warranted examining the acute and long-term effects of IMT on pO<sub>2</sub>, pCO<sub>2</sub>, Tension Time Index, and the subjective perception of dyspnea. Furthermore, since the FIT measure from TIRE PrO<sub>2</sub> testing is associated with propensity to fatigue, examination of the relationship between Tension Time Index and FIT would be extremely valuable due to the ease of obtaining FIT during several inspiratory maneuvers using the PrO<sub>2</sub> device.

## CONCLUSION

IMT *via* the TIRE and PrO<sub>2</sub> device elicited substantial improvements in inspiratory muscle performance, which substantially improved pulmonary function, 6-MWT distance ambulated, COPD symptoms, and the BODE index. Further investigation of the new and quite novel SMIP parameter and the TIRE method of IMT appears warranted in patients with COPD and other diseases in which inspiratory muscle performance is impaired.

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