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Test–Retest Reliability and Minimal Detectable Change in Chester Step Test and 1-Minute Sit-to-Stand Test in Long COVID Patients

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Abstract: The COVID-19 is a multiorgan disease that appeared in December 2019 in the Chinese province of Wuhan. It produces various clinical manifestations, although it mainly affects the respiratory system. Given these potentially detrimental long-term consequences of COVID-19, an appropriate assessment must be carried out to plan early rehabilitation interventions. To assess the persistent symptoms it produces, as well as exercise tolerance for a given exertion, stress testing is a feasible and cost-effective option. Therefore, the objective of this study was to provide test-retest reliability for the Chester Step Test and 1 minute Sit to Stand tests and to establish the minimum detectable change in Long-COVID patients. Method: This observational, descriptive, cross-sectional study was conducted following the STROBE guidelines. A total of 42 patients carried out, twice per partici-pant, the Chester Step and 1-Minute Sit-to-Stand (1min-STST) tests on two different days, with a five-day time lag between the initial measurement and the second measurement. Results: The Test-retest reliability for the Chester Step was excellent within session ICC (95% CI) 0.96 (0.93 to 0.98), being even better for the 1-STST, ICC (95% CI) 0.98 (0.96 to 0.99). Establishing a change of at least 16.96 steps (MDC90) or 20.15 steps (MDC95) and 1.89 stands (MDC90) or 2.71 stands (MDC95), respectively. Conclusions: The Chester Step and 1min-STST tests are reproducible and reliable tools to measure exercise tolerance in long COVID patients. The minimum detectable changes observed in the values recorded by the participants can be very useful for the evaluation of the effectiveness of interventions applied to these patients.

Keywords: submaximal exercise testing; COVID-19; exercise capacity; rehabilitation

1. Introduction

The first cases of COVID-19 (the infectious disease caused by SARS-CoV-2) were diagnosed in the Chinese province of Wuhan at the end of December 2019, and this disease was declared a pandemic on 12 March 2020 by the WHO [1]. The severity of COVID-19 may vary from asymptomatic to very severe [2], with one out of five patients being

asymptomatic [3]. Due to its multi-organ nature, it causes several clinical manifestations [4], although it mainly affects the respiratory system [5]. Other organs that can be affected by COVID-19 are the kidneys, heart, liver, nervous system, skin and muscles [5]. The clinical manifestations in phase-2 COVID-19 are fever, dry cough, loss of taste or smell, nasal congestion, sore throat, dyspnoea, muscle or joint pain, fatigue, headache, nausea and chest pain [4,6]. Moreover, some patients, even those with mild COVID-19 symptoms, may continue to experience symptoms after the initial recovery [7,8]. The literature shows that mild COVID-19 symptoms persist in one out of three patients (post-acute COVID-19) after 3 weeks, and that there are missing data about the persistence of these symptoms after 3 months (Long COVID) [9]. Fatigue is one of the most frequent persistent symptoms described, with dyspnoea, cough, headache, chest pain, decreased cognitive and mental state and loss of smell being other persistent symptoms that are also frequent, which can have a relevant impact on the patient's job and daily functioning [9]. Considering these consequences of COVID-19 are potentially harmful in the long term, an adequate evaluation is necessary to plan early rehabilitation interventions [10,11]. To evaluate the most prevalent persistent symptoms, such as fatigue and dyspnoea, as well as exercise tolerance against a specific task, effort tests are a reliable and cost-effective option [12,13]. The most widely used test for the assessment of the physical capacity in different respiratory, metabolic and heart or neurological diseases is the six-minute walk test (6MWT) [12]. Although a 6MWT can be performed in contexts with little resources, it is necessary to have specific technical requirements, such as a 30 metre-corridor, which is usually not available in hospitals and rehabilitation centres [12]. While previous studies have modified the length of the corridor [14,15], these have reported a decrease of 70 m in a 10 m-corridor in patients with non-communicable chronic diseases, exceeding the minimally relevant clinical difference [15], with such difference being potentially greater in older post-COVID-19 patients with long stays in bed [16]. However, other tests also evaluate physical capacity, such as the Chester step test (CST), where the aim is to climb and step down from a 30 cm-high step at a certain speed, increasing the latter progressively, and the 1 minute sit-to-stand test (1min-STST), where the patient stands up from, and sits on, an armless chair as many times as possible in 1 min [17]. These tests require little space, as compared to the 6MWT [18]. The CST is a progressive and submaximal test to predict aerobic capacity [19], and it was designed to estimate the exercise capacity of healthy participants, although it has also been used in patients with respiratory diseases [20,21]. Additionally, the 1min-STST is a widely used test that evaluates the muscle strength and resistance of the lower limbs, and it can be carried out in any healthcare environment, as it requires minimal equipment (conventional chair and chronometer), and it is performed easily and quickly [22]. Moreover, due to the fact that the capacity to stand from a chair is an important component to maintain the independence of older people and people with disabilities [23,24], the 1min-STST has been accepted as an indicator of the functional state of older people [25], showing high reliability [26] and strong correlations with the 6MWT, and it is used in the evaluation of chronic obstructive pulmonary disease [27]. Nevertheless, both the CST and 1min-STST are rarely used in patients who have recovered from COVID-19 [17]. Therefore, the aim of this study was to compare the CST and 1min-STST in post-COVID-19 patients. Furthermore, we calculated the test–retest reliability of both tests, obtaining the minimum detectable change, that is, the smallest change in the score that can be detected beyond the random error, with this being a basic indicator that can be used to determine the post-treatment effect based on the real changes observed in the scores of the patients [28].

2. Methods

This observational, descriptive, cross-sectional study was approved by the Research Ethics Committee of the Infanta Leonor University Hospital and Virgen de la Torre Hospital (Madrid, Spain) (registration number: R077-21/2021). All procedures were conducted following the "Strengthening the Reporting of Observational Studies in Epidemiology" (STROBE) guidelines [29]. The data were gathered in the Rehabilitation Unit of the Virgen

de la Torre Hospital in the Community of Madrid (Spain) between July 2021 and September 2021. The study was performed based on the Declaration of Helsinki and, before initiating it, we collected the informed consent of every person who voluntarily participated in this investigation.

2.1. Participants

The sample was selected by non-probabilistic convenience sampling among Long COVID patients referred by the Pneumology Service of the Infanta Leonor Hospital to the Rehabilitation Service of the Virgen de la Torre Hospital, who were registered in the database to perform a previous evaluation before initiating the respiratory rehabilitation programme. To be considered as patients with Long COVID, they had to present asthenia, general malaise, lack of concentration and/or memory failures lasting more than 4 weeks after the infection. All participants voluntarily agreed to participate in the study and were required to be able to understand and complete the evaluations. The tests excluded those patients with cognitive deterioration, hemodynamic instability, previous diagnosis of chronic respiratory disease (COPD, HP, ILD, asthma and bronchiectasis), central/peripheral neurological affectation secondary to COVID-19, trauma or rheumatological affectation that prevents the correct realization of the functional tests, modified dyspnoea scale of the Medical Research Council with a score of over 2 points, or failure to provide the informed consent.

2.2. CST

CST was performed guided by the rhythm of a recording of acoustic signals from a metronome. In the first level, the patients were required to walk up and down a 30 cm-high step at a rate of 15 times per minute, increasing the number of steps by 10 every 120 s. The maximum test time was 10 min [20]. During the test, heart rate and blood oxygen saturation (SpO_2), using a pulse oximeter, and dyspnoea, using the modified Borg scale, were monitored. This monitoring was performed before the start of the test, at the end of each level of the test, and immediately after their completion. Before and at the end of the test, leg fatigue was also assessed according to the modified Borg scale. The test was terminated when: (1) the patient was not able to maintain the prescribed pace; (2) limiting symptoms such as dizziness, dyspnoea or headache appeared, which the patient had to point out as soon as they were perceived; (3) if 90% of the maximum predicted heart rate (HRmax) calculated by the equation HRmax = 210 (0.65 × age) was reached; (4) in the event of desaturation, with SpO_2 desaturation being considered less than 90% or a decrease of 4% below baseline saturation; or (5) if the patient decided to stop the test. The results are presented by the number of test levels completed and the number of steps climbed.

2.3. One-Minute Sit-to-Stand Test

The test was performed by recording the number of times the participant was able to stand up from and sit on a chair within 1 min, using a chair without armrests with a seat height of 17 inches (43.2 cm), with rubber tips on the legs, and placed against a wall to prevent it from moving. The participant sat in the centre of the chair, with his or her back straight and arms crossed over the chest, and feet approximately shoulder-width apart, placed on the floor at an angle slightly behind the knees. Prior to the start of the test, the participant performed two test repetitions. During the test, the patient was encouraged to stand up, performing the complete movement, as many times as possible in 1 min [30]. Before, during and at the end of the test, heart rate, blood oxygen saturation (SpO_2) by pulse oximeter, and lower extremity fatigue by modified Borg scale, were monitored. The test was terminated when: (1) limiting symptoms such as dizziness, dyspnoea or headache appeared, which the patient had to report as soon as they were perceived; (2) if the patient reached 90% of the maximum predicted heart rate (HRmax), calculated by the equation HRmax = 210 (0.65 × age); (3) if desaturation occurred, with SpO_2 desaturation being considered less than 90% or a decrease of 4% below baseline; (4) or if the patient voluntarily

decided to stop the test. The results are presented according to the number of times the participant stood up and sat down.

2.4. Study Procedures

In this study, a repeated measures concordance design was used to assess test–retest reliability in CST and 1 min-STST, comparing performance on two different days, with a five-day time lag between the initial measurement and the second measurement, to ensure that there would be no overlap and learning effect between tests and no changes in functional capacity in Long COVID patients. All participants were scheduled for dyspnoea assessment using the mMRC scale and performance of the CST and 1min-STST field tests. Before starting the test, the weight of all participants without shoes was measured using a "Detecto" scale (Lafayette Instruments Company, IN, USA) with a measuring range of 0–150 kg and an accuracy of 200 g. Height was measured with a "Holtain" tallimeter (Holtain Limited), with a measuring range of 60–213 cm and an accuracy of one millimetre, with the participants barefoot, with feet parallel and together, and standing, with arms outstretched to the sides. The participants' heart rate and oxygen saturation were monitored using the pulse oximeter MC300C1C Beijing Choice Electronic®.

2.5. Sample Size Calculation

For the calculation of the sample size, a method was employed that determines the number of participants using an estimate of the intraclass correlation coefficient [31]. Thus, it was determined that it would be necessary to recruit a minimum of 40 individuals to carry out the study, with an acceptable reliability of 0.60 (minimum acceptable value of the acceptable ICC) and an expected reliability of 0.80 (expected ICC value), with a power of 90% and a significance level of 5%. Due to the nature and characteristics of the study, a loss of 5% of the sample was assumed.

2.6. Data Analysis

The statistical analysis was performed using the SPSS statistical software (Statistical Package for Social Sciences 25, SPSS Inc., Chicago, IL USA). The data are presented as mean, standard deviation, 95% confidence interval and minimum and maximum range. The intraclass correlation coefficient (ICC) was used to assess test-retest reliability when using the Chester Step and Sit-to-Stand tests with a 5-day time interval in long COVID pa-tients. Reliability levels were established according to the following classification: excel-lent reliability (ICC $\geq$ 0.90), good reliability (0.90 > ICC $\geq$ 0.70), fair reliability (0.70 > ICC $\geq$ 0.40) and poor reliability (ICC < 0.40) [32]. The precision of the reliability results was measured by Standard Error of Measurement (SEM), which was calculated as Standard Deviation of difference score/$\sqrt{2}$ [33]. Minimum detectable change (MDC) was calculated as SEM $\times$ $\sqrt{2}$ $\times$ 1.96 for a 95% confidence level and as SEM $\times$ $\sqrt{2}$ $\times$ 1.65 for a 90% confidence level. Additionally, Bland-Altman graphs were used to assess the agreement between meas-urements. All statistical tests were interpreted using a 5% significance level ($p < 0.05$).

3. Results

A total of 42 participants were initially recruited. All of them completed the study and none of them reported adverse effects during the measurements. The sample was constituted by 20 men (48%) and 22 women (52%). The age range of the participants was 33–79 years, with an average age of 53.8 $\pm$ 10.2 years. The mean hospitalisation length was 21.38 $\pm$ 38.99 days, with a wide range, from 10 to 191 days. The data about anthropometric and hospitalisation variables are shown in Table 1.

The data about physiological variables and subjective variables of dyspnoea and fatigue, as well as their comparison between measurement 1 and measurement 2 in the CST and 1min-STST are presented in Table 2.

Table 1. Descriptive data measurements for anthropometric variables, age, BMI and hospitalisation days.

	Mean ± SD	**(95% CI) Min–Max**
Age (years)	51.6 ± 9.3	(50.6 to 57.0) 33–79
Weight (kg)	84.0 ± 18.1	(78.6 to 89.6) 45.1–125.0
Height (cm)	165.2 ± 9.4	(162.3 to 165.2) 145–186
BMI (kg/m^2)	30.5 ± 5.1	(29.0 to 32.2) 17.4–40.2
Hospitalisation (days)	21.4 ± 39.0	(9.2 to 33.5) 10.0–191.0

Abbreviations: SD, standard deviation; CI, confidence interval.

Table 2. Physiological variables and subjective variables of dyspnoea and fatigue.

		Chester Test			**Sit-to-Stand**		
		Trial 1	**Trial 2**	***p*-Value**	**Trial 1**	**Trial 2**	***p*-Value**
Saturation Basal (%)	Mean ± SD (95% CI)	96.4 ± 1.8 (95.8–97.0)	96.2 ± 2.0 (95.5–96.9)	0.545	96.5 ± 1.4 (96.08–96.9)	96.7 ± 1.3 (96.2–97.1)	0.344
	(min–max)	(90.0–99.0)	(90.0–100.0)		(93.0–99.0)	(92.0–99.0)	
Heart Rate Basal (lpm)	Mean ± SD (95% CI)	84.0 ± 14.8 (79.2–88.8)	85.6 ± 14.4 (81.0–90.3)	0.488	83.6 ± 13.7 (79.3–87.9)	84.7 ± 13.8 (80.4–89.0)	0.455
	(min–max)	(51–114)	(51–112)		(54–108)	(59–115)	
Saturation Final (%)	Mean ± SD (95% CI)	94.6 ± 2.5 (93.8–95.4)	94.6 ± 2.6 (93.8–95.52)	0.833	93.8 ± 3.3 (92.8–94.9)	91.4 ± 14.2 (87.0–95.9)	0.327
	(min–max)	(89.0–99.0)	(89.0–98.0)		(87.0–99.0)	(85.0–99.0)	
Heart Rate Final (lpm)	Mean ± SD (95% CI)	108.3 ± 19.4 (102.1–114.5)	109.5 ± 18.3 (103.6–115.4)	0.384	118.4 ± 27.7 (109.7–127.0)	118.8 ± 27.2 (110.3–127.3)	0.655
	(min–max)	(65–146)	(62–146)		(77–155)	(73–160)	
BORG	Mean ± SD (95% CI)	3.9 ± 1.8 (3.2–4.5)	4.0 ± 1.8 (3.4–4.6)	0.626	4.4 ± 1.8 (3.9–5.0)	5.1 ± 1.9 (4.1–5.7)	0.413
	(min–max)	(0–7)	(0–8)		(0–7)	(0–7)	
Fatigue LL	Mean ± SD (95% CI)	4.0 ± 2.1 (3.3–4.7)	4.3 ± 1.8 (3.7–4.9)	0.381	4.4 ± 2.1 (3.7–5.2)	4.5 ± 2.4 (3.8–5.1)	0.983
	(min–max)	(0–8)	(0–8)		(0–10)	(0–9)	

Abbreviations: SD, standard deviation; LL, lower limbs.

Test–Retest Reliability

The test–retest reliability obtained between the initial measurement and the measurement recorded 5 days later was excellent for both the CST and 1min-STST (Table 3). For the CST, MDC_{90} was set at a change of 12% with respect to the initial measurement (16.96 steps), whereas MDC_{95} was set at a change of 15% (20.15 steps). In the 1min-STST, a lower change percentage was required to detect significant differences: MDC_{90} at 8% (1.89 stands) and MDC_{95} at 12% (2.71 stands). The descriptive statistics, ICC and 95% CI associated, SEM, MDC_{90} and MDC_{95} for the concordance between sessions are shown in Table 3.

Table 3. Descriptive statistics and the test–retest reliability observed.

Test–Retest Reliability for Chester Step (Trial 1 vs. Trial 2)						
Mean ± SD			**ICC (95% CI)**	**SEM**	**MDC_{90}**	**MDC_{95}**
Trial 1	**Trial 2**	***p***				
137.76 ± 72.16	138.80 ± 73.35	0.093	0.96 (0.93 to 0.98)	7.27	16.96 (12%)	20.15 (15%)
Test–retest reliability for sit-to-stand (Trial 1 vs. Trial 2)						
Mean ± SD			ICC (95% CI)	SEM	MDC_{90}	MDC_{95}
Trial 1	Trial 2	*p*				
22.47 ± 5.93	22.85 ± 5.58	0.196	0.98 (0.96 to 0.99)	0.81	1.89 (8%)	2.71 (12%)

Abbreviations: SD, standard deviation; ICC, intraclass correlation coefficient; CI, confidence interval, SEM, standard error of measurement; MDC, minimal detectable change.

Bland Altman plots were used to analyse inter-test reliability (Figure 1).

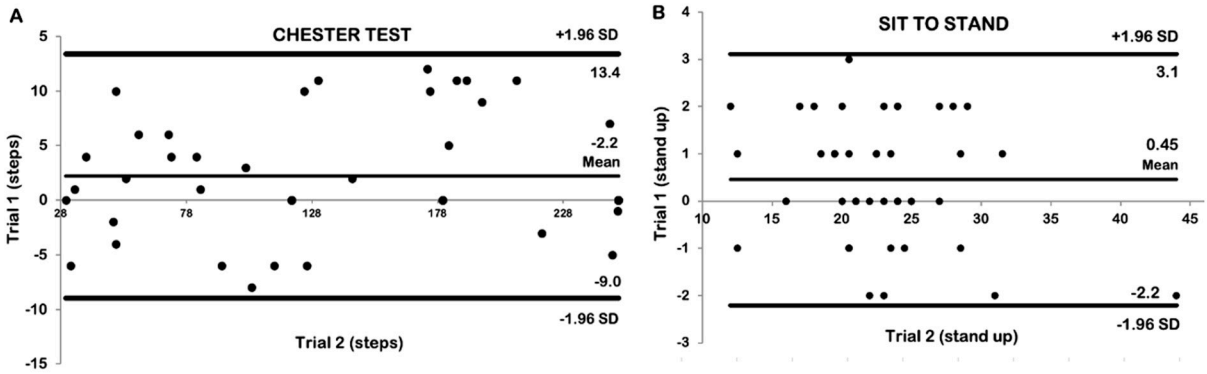

Figure 1. Bland-Altman plot Inter-rater reliability; The bias and limits of agreement (black lines) are displayed for CST (**A**) and 1min-STST (**B**). The mean score is represented on the x-axis and the difference between sessions (mean of the differences) is represented on the y-axis (mean difference ± 1.96 SD).

4. Discussion

To the best of the authors' knowledge, this is the first study about the test–retest reliability of the CST and 1min-STST in Long COVID patients, additionally establishing the MDC in both tests. Given the diverse characterisation of the effects of COVID-19 and their great impact on the quality of life, it is very important to determine the reliability and reproducibility of the tests that evaluate effort tolerance, in order to implement efficient and safe physical exercise protocols, with the aim of accurately objectifying the changes and adaptations that such protocols may generate. The evaluations were carried out in both tests with at least 7 days between evaluations; this period was established as the most adequate in test–retest reliability studies [34]. Some reliability studies, such as that of Bradley et al. [35], used the correlation coefficient; however, we conducted our test–retest reliability analysis using ICC, as recommended by Koo et al. [36], since it is considered to be a more accurate method.

The CST proved to be a reliable and reproducible tool, showing excellent test–retest reliability within the session (ICC (95% CI) 0.96 (0.93 to 0.98)). Several studies have also demonstrated the reliability of CST, both in a healthy population [18,37] and in people with chronic respiratory diseases [38,39]. The 1min-STST also presented excellent test–retest (ICC (95% CI) 0.98 (0.96 to 0.99)), even better than that of the CST in this population. This test has also proved to be a valid and reliable tool in people with different pathologies [40–43]. Therefore, these tests may be valid and adequate to assess exercise tolerance in this and other populations.

The Bland–Altman plots showed a disagreement ranging from 13.3 to – -8 steps for reliability in the CST and from 3.1 to –2.2 stands in the 1min-STST.

The 6MWT is the most widely used method for the evaluation of exercise tolerance, although it has some drawbacks, such as the need for a long corridor in order to be carried out [12]. Therefore, we believe that the CST and 1min-STST are adequate and simple alternatives that can be easily used in contexts where time and space are limited, since they do not require expensive and sophisticated equipment to evaluate the exercise capacity, thus they can be conducted in home environments, which is undoubtedly an added value. Moreover, a recent study has pointed out that both tests are significantly correlated with the 6MWT in patients who were recovering from the effects of COVID-19 [17], thus both alternative tests are solid and recommendable.

Furthermore, due to their ease of completion, both face-to-face and remotely [11,44], especially in the case of the 1min-STST, which has been recommended by the literature in tele-rehabilitation programmes, these instruments are very valid in situations such as the one caused by the COVID-19 pandemic, where lockdowns were established and the

mobility of the population was restricted [45–48]. On the other hand, COVID-19 sequelae monitoring programs advocate for the assessment of physical capacity [49]. Given the significant number of patients exhibiting these sequelae, primary care has been compelled to accommodate this patient population [50]. These low-cost tools have already been employed in primary care-based rehabilitation programs, demonstrating their ability to detect post-intervention differences [46]. In summary, our data contributes to the clinicians' ability to use these tools with knowledge of their reliability, particularly in understanding the MCID. This knowledge will assist primary care professionals and tele-rehabilitation practitioners in determining the effectiveness of their interventions.

Consequently, we believe that the 1min-STST and CST are valid, reliable and reproducible tools for the evaluation of effort tolerance in people who have suffered from COVID-19.

The MDC was also assessed in this study, which is the smallest measure change that can be objectified and cannot be attributed to a measurement error [28]. Based on the MDC established in the present study, the people who recovered from the effects of COVID-19 required a difference of 17 steps made during the CST to be considered a significant change (MDC_{90}: 16.96 (12%); MDC_{95}: 20.15 (15%)). Regarding the 1min-STST, it was necessary to stand up from the chair at least two more times with respect to the baseline measurement in order to consider that the patient's situation has really changed (MDC_{90}: 1.89 (8%); MDC_{95}: 2.71 (12%)). The MDC of these tests has been previously established for other populations [51,52], but not for post-COVID-19 patients, thus we cannot compare our data with those of previous studies. However, we consider that the values recorded by the participants in this study can be useful in the evaluation of the effectiveness of interventions applied to these patients.

We would like to point out the importance of expressing the changes in the tests that evaluate functional performance as percentages, which is usual in the assessment of the respiratory function [53,54], and not as an absolute value, since the changes caused by a treatment or a pathology occur in the context of changes caused by the natural deterioration of older people, growth, or very different morphologies and anthropometric values. Otherwise, the results may be misinterpreted, potentially overestimating the effect of an intervention, or undervaluing the deterioration caused by a pathology. An example of that is the typical inverted U-shaped evolution of Duchenne's muscular dystrophy, where a functional plateau occurs at the age of 7 years; at that point, the initial gains that can be attributed to growth are overcome by deterioration, due to the progression of the disease [55].

Lastly, although our results indicate that these tests can be an adequate alternative to evaluate tolerance to physical exercise, it is important to take into account that certain people with musculoskeletal pathologies, overweight or balance problems may not be capable of adequately performing the tests, which has a negative impact on performance. Therefore, it would be appropriate, in these cases, to resort to modified versions, such as the 30-second sit-to-stand test or the 5-times sit-to-stand test.

5. Limitations

The present study has some limitations that must be pointed out. One of these limitations is that the measurements may be affected by factors such as motivation and enthusiasm in the realisation of the test by some of the patients; however, this variability was reduced by having the measurements recorded by evaluator physiotherapists with extensive experience with functional tests. Another limitation was the impossibility of using a gas analyser, due to its high cost, to evaluate oxygen kinetics during the realisation of the tests. On the other hand, the number of participants was small and with great variability in terms of days of hospitalization caused by COVID-19.

6. Conclusions

In conclusion, the present study indicates the reliability and reproducibility of the CST and the 1min-STST as a measure of exercise tolerance and indicates them as valid alternatives in situations with limited material resources. The study also establishes the MDC in Long COVID patients to identify a real change in the patient's condition as a result of an intervention protocol.

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Conflicts of Interest: The authors declare no competing interest.

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