Obese patients with long COVID-19 display abnormal hyperventilatory response and impaired gas exchange at peak exercise

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Aim: To analyze the impact of obesity on cardiopulmonary response to exercise in people with chronic post-coronavirus disease 2019 (COVID-19) syndrome. Patients & methods: Consecutive subjects with chronic post-COVID syndrome 6 months after nonsevere acute infection were included. All patients received a complete clinical evaluation, lung function tests and cardiopulmonary exercise testing. A total of 51 consecutive patients diagnosed with chronic post-COVID-19 were enrolled in this study. Results: More than half of patients with chronic post-COVID-19 had a significant alteration in aerobic exercise capacity (VO2peak) 6 months after hospital discharge. Obese long-COVID-19 patients also displayed a marked reduction of oxygen pulse (O2pulse). Conclusion: Obese patients were more prone to have pathological pulmonary limitation and pulmonary gas exchange impairment to exercise compared with nonobese COVID-19 patients.

Plain language summary: In this study, the cardiopulmonary response to exercise in people with chronic post-COVID-19 syndrome was analyzed. More than half of patients diagnosed with chronic post-COVID-19 had reduced exercise capacity 6 months after hospital discharge. In addition, patients with chronic post-COVID-19 syndrome who were overweight or obese displayed exaggerated hyperventilation along with an impairment of oxygenation at peak exercise.

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Individuals with obesity have an increased risk of hospitalization, increased need for intensive care and increased risk of death [1–4]. As clinicians continue to learn about and treat coronavirus disease 2019 (COVID-19), growing evidence suggests that symptoms after acute infection may persist long after the acute infectious phase. Post-COVID-19 conditions are characterized by long-term consequences persisting or appearing after the typical convalescence period of COVID-19. The so-called chronic post-COVID-19 syndrome is defined as postacute COVID-19 syndrome with persistent symptoms after 12 weeks [5–7]. Reported symptoms span a large breadth of cardiopulmonary and neurologic complaints including fatigue, palpitations, chest pain and breathlessness [5–7]. As we are just beginning to understand the long-term implications of COVID-19 on health, old age, being female, poor prepandemic mental health, poor general health and being overweight or obese, confer an increased risk of developing chronic post-COVID-19 syndrome [6–8].
Respiratory symptoms dominate both the acute phase and longer-term sequelae of COVID-19 and exercise dyspnea and fatigue are the most common complaints [9]. Evaluation of aerobic capacity can provide further insights into the exercise intolerance commonly observed in patients with chronic post-COVID-19 [9–15]. Typical cardiopulmonary exercise testing (CPET) findings in chronic post-COVID-19 patients include a decrease in VO2peak, decreased anaerobic threshold, exaggerated hyperventilatory response, preserved ventilatory reserve and decreased oxygen extraction, all suggestive of skeletal muscle deconditioning [9–15]. Several CPET studies have been designed to conduct subgroup analyses of patients presenting with comorbidities such as obesity, cardiovascular conditions and chronic lung diseases. Whereas obesity is a well-recognized risk factor for severe COVID-19 and hospital admission for postacute COVID-19, whether obesity affects long COVID-19 cardiopulmonary response to exercise has not been extensively studied. The objective of this study was to determine cardiopulmonary function during exercise 6 months after hospital discharge for COVID-19 and to analyze the impact of obesity on cardiopulmonary response to exercise in these patients compared with non-COVID-19 obese people.

**Methods**

**COVID-19 patients**

Consecutive COVID-19 patients were included following evaluation at the University Hospital Martinique, France, from October 2020 to June 2021. Martinique is a French Caribbean island classified high in terms of global human development at the world level. Martinique has a population of 358,749 inhabitants (January 1, 2020). Patients were included during the third COVID-19 epidemic thread. A total of 11,739 COVID-19 cases were diagnosed in Martinique and 10% of patients were admitted to the University Hospital of Martinique. Patients with a reverse transcription-polymerase chain reaction (RT-PCR)-confirmed SARS-CoV-2 infection who were admitted to COVID-19 medical wards were included. Patients were included if they presented at the pluridisciplinary consultation with persistent symptoms after a 6-month follow-up. Only patients with noncritical COVID-19 (i.e., mild disease, score: 3–4 on the WHO 9-point ordinal clinical progression scale) were included in this study [14]. Clinical examination and CT scans of the chest were normal at the time of the patient’s inclusion. Criteria for chronic post-COVID-19 syndrome were a combination of symptoms including fatigue, shortness of breath, chest pain, palpitation and cognitive impairment [5]. Patients were invited to take part in an evaluation program that included lung function and cardiopulmonary exercise testing. No recommendations were given to the patients to refrain from taking their usual medications for diabetes or hypertension.

**Obese non-COVID-19 patients**

During the same period of inclusion, functional parameters of obese non-COVID-19 patients with no history of cardiopulmonary diseases were included. Complete clinical and pulmonary and cardiovascular functional testing was performed for the purpose of preoperative evaluation before bariatric surgery. This group of patients represents a random sample of individuals who came for bariatric surgery at the same time chronic post-COVID-19 patients were recruited.

**Study design**

Six months after hospital discharge, all patients received a complete clinical evaluation, spirometry and cardiopulmonary exercise testing. A statement on written informed consent in line with the Journal's policy on studies in human subjects was obtained from all patients. The study was conducted in accordance with the amended Declaration of Helsinki, registered in the Trials Registry and approved by the local Institutional Review Board.

**Spirometry & body plethysmography**

Standard spirometry including forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1) and total lung capacity (TLC) was measured by body plethysmography in a Jaeger-Masterlab cabin using guidelines of the American Thoracic Society (ATS) and the European Respiratory Society. Lung diffusion capacity for carbon monoxide (DLCO) was measured by the single-breath technique. A restrictive ventilatory pattern was defined as a combination of FEV1/FVC > 0.70 and FVC <80% of predicted.

**Cardiopulmonary exercise testing**

Cardiopulmonary exercise testing (Case, GE Healthcare, equipped with a PowerCube-Ergo, Ganshorn Medizin Electronic GmbH, Niederlauer, Germany) was performed according to stan-
dardized procedures on an electromagnetically braked cycle ergometer, as recommended by the ATS/American College of Chest Physicians (ACCP) [16]. Factors, such as age and BMI, were taken into account according to the predicted VO2 Wasserman’s equation for males: VO2max (L/min) = [0.79 × height − 60.7] × (50.72 − 0.372 × age) + 6 × (BMI − (0.79 × height − 60.7)) and Wasserman’s equation for females: [0.65 × height − 42.8] + 43 × (22.78 − 0.17 × age) + 6 × (BMI − (0.65 × height − 42.8)). VO2peak was expressed as the percent of predicted. In addition, because VO2peak expressed relative to body weight (mL·kg−1·min−1) has been shown to underestimate VO2 in obese subjects, VO2peak was scaled relative to the body weight raised to the power of 0.75 (mL·kg−0.75·min−1) [16].

Following a 3-min warm-up, a progressively incremental (10 W/min) exercise was started until volitional fatigue. Subjects were continuously monitored using 12-lead ECG and pulse oximetry (SpO2). Breath-by-breath cardiopulmonary data were measured at rest, warm-up and incremental exercise testing. Minute ventilation (VE), oxygen uptake (VO2) and carbon dioxide output (VCO2) were recorded as concurrent 10-s moving averages and expressed as the percent of predicted values by Wasserman’s equation. Calibration procedures for O2 and CO2 analyzers and the flow rate were run before each test as recommended by the manufacturer (Ganshorn Medizin Electronic GmbH, Niederlauer, Germany). In brief, calibration for O2 and CO2 analyzers was performed using two reference gases, pure air and a mixture of 16% O2 and 5% CO2. Flow rate calibration was performed using a calibrated 3L syringe. During the study period, mean values between qualified replicate tests performed weekly on control subjects were 2.5 ± 2.3%, 3.1 ± 1.2% and 2.5 ± 1.7% for peak VO2, VCO2 and VE, respectively. The ventilation anaerobic threshold was determined by the V-slope method [17,18]. Ventilatory efficiency, as indicated by the increment in VE relative to VCO2 (VE-VCO2 slope) was calculated offline as a linear regression function using 10-s-averaged values and excluding the nonlinear part of the relationship after the respiratory compensation point [17]. Peak oxygen pulse (O2 pulse) was calculated and expressed in ml/beat and as the percentage of the predicted value by dividing the predicted peak VO2 by the predicted peak heart rate. Assuming normal values of arterial oxygen content and C(a-v)O2 at peak effort, peak stroke volume in mm can then be estimated as (oxygen pulse/15) × 100, where oxygen pulse is in mm/beat [18]. Patient effort was considered maximal if two of the following occurred: predicted maximal work was achieved, age-predicted maximal heart rate was achieved, ventilatory O2 equivalent VE/VO2 > 45 and respiratory exchange ratio (RER, i.e. volume of carbon dioxide produced/volume of oxygen consumed) > 1.10, as recommended by the ATS/ACCP [17]. Symptoms and subjective ratings of perceived exertion were recorded to estimate exertion level.

Statistical analysis
For all descriptive and inferential analyses, the assumption of normal distribution of the data was analyzed. Means and standard deviations are reported for normally distributed variables and median and min–max range are reported for nonnormally distributed variables. Categorical variables are presented as frequencies or percentages. Student t-tests and Chi-square tests were used for group comparisons. Based on early data on peak VO2 from COVID-19 patients, a sample size of at least 20 patients per group would be sufficient to detect a difference of 10% in predicted VO2 (a minimal clinically relevant difference in cardiopulmonary diseases) between groups (statistical power: 80%, alpha error: 5%). The level of statistical significance was set at p < 0.05. All statistical analyses were conducted using SAS software 9.4 for Windows (SAS Institute, NC, USA).

Results
Using post-COVID-19 syndrome criteria, 60 consecutive patients with the diagnosis of chronic post-COVID-19 were enrolled. A total of 9 patients (15.0%) who were unable to perform exercise were excluded. The final population included 51 patients (Table 1). Dyspnea and fatigue were the most frequent symptoms of chronic post-COVID-19 syndrome. A restrictive ventilatory pattern was observed in 59% of cases. Detailed quantitative lung function parameters are displayed in Table 2. Altered aerobic capacity (VO2peak <75% of predicted values) was observed in 53% of cases. Mean aerobic capacity was significantly impaired (VO2peak = 16.2 ± 4.8 mL·kg−0.75·min−1, 72 ± 13% of predicted; Table 2). Characteristics of chronic post-COVID-19 patients were then stratified according to BMI below or above 30 kg·m−2. Compared with nonobese COVID-19 patients (BMI <30 kg·m−2), obese COVID-19 patients (BMI >30 kg·m−2) had similar age, sex ratio, comorbidities and duration of hospital stay (Table 1). Compared with nonobese COVID-19 patients, obese COVID-19 patients had lower lung volumes (Table 2), while the lung transfer coefficient for carbon monoxide (KCO) was higher in obese patients. Despite similar VO2peak lowering, obese COVID-19 patients exhibited increased VE-VCO2 slope, reduced ventilatory reserve and lower
Table 1. Pulmonary function and cardiopulmonary exercise testing in chronic post-COVID-19 patients.

| Characteristics                        | All COVID-19 patients (n = 51) | Nonobese (n = 18) | Obese (n = 33) | p-value |
|-----------------------------------------|---------------------------------|-------------------|----------------|---------|
| **Clinical variables**                  |                                 |                   |                |         |
| Age, years (mean ± SD)                  | 60 ± 11                         | 64 ± 13           | 58 ± 10        | 0.071   |
| Men, n (%)                              | 30 (59)                         | 12 (67)           | 18 (55)        | 0.295   |
| BMI, kg/m² (mean ± SD)                  | 31 ± 6                          | 25 ± 2            | 34 ± 5         | <0.001† |
| **Presence of cardiovascular risk factors** |                                 |                   |                |         |
| History of hypertension, n (%)          | 20 (39)                         | 8 (44)            | 12 (36)        | 0.394   |
| History of diabetes, n (%)              | 14 (28)                         | 4 (22)            | 10 (30)        | 0.392   |
| History of COPD, n (%)                  | 5 (10)                          | 3 (17)            | 2 (6)          | 0.230   |
| **Length of hospital stay for acute COVID-19** |                                 |                   |                |         |
| Days (mean ± SD)                        | 7.4 ± 2.1                       | 7.4 ± 2.6         | 7.4 ± 1.8      | 0.955   |
| **Time from hospital discharge to functional evaluation** |                                 |                   |                |         |
| Days (mean ± SD)                        | 189 ± 12                        | 187 ± 12          | 190 ± 13       | 0.389   |
| **Symptoms of chronic COVID-19**        |                                 |                   |                |         |
| Fatigue, n (%)                          | 46 (90)                         | 16 (89)           | 30 (91)        | 0.585   |
| Dyspnea, n (%)                          | 43 (84)                         | 12 (67)           | 31 (94)        | 0.024†  |
| Chest pain, n (%)                       | 13 (25)                         | 3 (17)            | 10 (20)        | 0.501   |
| **Pulmonary function test**             |                                 |                   |                |         |
| Predicted FEV₁ (%)                      | 79 ± 14                         | 87 ± 13           | 75 ± 13        | 0.002²  |
| Predicted FVC (%)                       | 77 ± 15                         | 82 ± 16           | 74 ± 14        | 0.045†  |
| FEV₁/FVC (%)                            | 84 ± 8                          | 84 ± 7            | 83 ± 9         | 0.641   |
| FRC (%)                                 | 79 ± 19                         | 81 ± 18           | 77 ± 19        | 0.514   |
| TLC (%)                                 | 73 ± 12                         | 79 ± 9            | 69 ± 12        | 0.003†  |
| ERV (%)                                 | 58 ± 27                         | 67 ± 25           | 53 ± 28        | 0.080   |
| RV (%)                                  | 80 ± 25                         | 71 ± 25           | 86 ± 24        | 0.043³  |
| DLCO (%)                                | 77 ± 13                         | 77 ± 11           | 77 ± 14        | 0.882   |
| KCO (%)                                 | 105 ± 12                        | 100 ± 11          | 108 ± 12       | 0.029³  |
| **Cardiopulmonary exercise testing**    |                                 |                   |                |         |
| Peak workload (% predicted)             | 54 ± 15                         | 52 ± 14           | 56 ± 16        | 0.458   |
| Peak VO₂ (L.min⁻¹)                      | 1.44 ± 0.50                     | 1.28 ± 0.41       | 1.53 ± 0.53    | 0.089   |
| Peak VO₂ (mL.Kg⁻¹.min⁻¹)                | 16.2 ± 4.8                      | 17.1 ± 4.5        | 15.7 ± 5.0     | 0.326   |
| Peak VO₂ (% predicted)                  | 72 ± 13                         | 70 ± 11           | 73 ± 14        | 0.436   |
| Peak RER                                | 1.12 ± 0.13                     | 1.13 ± 0.12       | 1.12 ± 0.10    | 0.886   |
| Peak VE/VO₂                             | 36 ± 6                          | 35 ± 5            | 39 ± 7         | 0.011†  |
| Peak VE/VCO₂                            | 33 ± 6                          | 32 ± 6            | 34 ± 6         | 0.261   |
| Ventilatory reserve (%)                 | 31 ± 20                         | 40 ± 14           | 25 ± 21        | 0.011†  |
| VE VCO₂ slope                           | 32 ± 4                          | 34 ± 6            | 31 ± 4         | 0.045⁵  |
| Peak O₂ pulse (%)                       | 66 ± 13                         | 68 ± 12           | 66 ± 13        | 0.567   |
| Peak heart rate (%)                     | 87 ± 11                         | 90 ± 11           | 85 ± 10        | 0.089   |
| Peak heart rate used (%)                | 74 ± 22                         | 80 ± 25           | 70 ± 21        | 0.135   |
| Peak systolic pressure (mmHg)           | 197 ± 29                        | 199 ± 27          | 197 ± 30       | 0.798   |
| Peak diastolic pressure (mmHg)          | 98 ± 21                         | 102 ± 23          | 97 ± 20        | 0.460   |
| Peak SpO₂ (%)                           | 98 ± 21                         | 98 ± 2            | 96 ± 3         | 0.036⁷  |
| Peak Borg scale dyspnea                 | 5 [3–8]                         | 5 [3–8]           | 5 [3–8]        | 0.538   |
| Peak Borg scale leg fatigue             | 7 [3–8]                         | 6.5 [3–8]         | 7 [3.5–8]      | 0.586   |

Data are presented as mean ± standard deviation (SD) and median (IRQ); peak heart rate (% predicted 220-age).

¹ Statistical significance set at p < 0.05.

AT: Anaerobic threshold; Borg: Modified Borg scale (0-10) for rate of perceived exertion scale; bpm: Beat per minute; COPD: Chronic obstructive pulmonary disease; DLCO: Diffusion capacity of the lung for carbon monoxide; ERV: Expiratory reserve volume; FEV₁: Forced expiratory volume after 1 second; FRC: Functional residual capacity; FVC: Forced vital capacity; KCO: Transfer coefficient of the lung for carbon monoxide; RER: Respiratory exchange ratio; RV: Residual volume; SpO₂: Pulse oximetry; TLC: Total lung capacity; VCO₂: Pulmonary carbon dioxide output; VE: Minute ventilation; VO₂: Oxygen uptake.
Table 2. Pulmonary function and cardiopulmonary exercise testing in obese chronic post-COVID-19 and obese non-COVID-19 patients.

| Clinical variables                      | Obese COVID-19 patients (n = 33) | Obese non-COVID-19 patients (n = 29) | p-value |
|-----------------------------------------|-----------------------------------|-------------------------------------|---------|
| Age, years (mean ± SD)                  | 58 ± 10                           | 50 ± 13                             | 0.008   |
| Men, n (%)                              | 18 (55)                           | 6 (21)                              | 0.009   |
| BMI, kg/m2 (mean ± SD)                  | 34 ± 5                            | 41 ± 8                              | <0.001  |
| History of hypertension, n (%)          | 12 (36)                           | 12 (41)                             | 0.796   |
| History of diabetes, n (%)              | 10 (30)                           | 12 (41)                             | 0.431   |
| Pulmonary function test                 |                                   |                                     |         |
| Predicted FEV1 (%)                      | 75 ± 13                           | 74 ± 8                              | 0.721   |
| Predicted FVC (%)                       | 74 ± 14                           | 76 ± 8                              | 0.501   |
| FEV1/FVC (%)                            | 83 ± 9                            | 85 ± 4                              | 0.274   |
| FRC (%)                                 | 77 ± 19                           | 76 ± 12                             | 0.808   |
| TLC (%)                                 | 69 ± 12                           | 76 ± 9                              | 0.013†  |
| Cardiopulmonary exercise testing        |                                   |                                     |         |
| Peak workload (% predicted)             | 56 ± 16                           | 62 ± 12                             | 0.104   |
| Peak VO2 (L.min⁻¹)                      | 1.53 ± 0.53                       | 1.68 ± 0.66                         | 0.381   |
| Peak VO2 (mL.kg⁻0.75.min⁻¹)             | 15.7 ± 5.0                        | 15.3 ± 2.7                          | 0.702   |
| Peak VO2 (% predicted)                  | 73 ± 14                           | 72 ± 14                             | 0.780   |
| Peak RER                                | 1.12 ± 0.10                       | 1.16 ± 0.10                         | 0.831   |
| Peak VE/VO2                             | 39 ± 7                            | 34 ± 5                              | 0.002†  |
| Peak VE/VO2                             | 34 ± 6                            | 31 ± 4                              | 0.026†  |
| Ventilatory reserve (%)                 | 25 ± 21                           | 39 ± 16                             | 0.005†  |
| VE VCO₂ slope                           | 31 ± 4                            | 32 ± 6                              | 0.438   |
| Peak O₂ pulse (%)                       | 66 ± 13                           | 76 ± 12                             | 0.003†  |
| Peak heart rate (%)                     | 85 ± 10                           | 87 ± 7                              | 0.3716  |
| Heart rate reserve used (%)             | 70 ± 21                           | 73 ± 15                             | 0.525   |
| Peak systolic pressure (mmHg)           | 197 ± 30                          | 195 ± 32                            | 0.080   |
| Peak diastolic pressure (mmHg)          | 97 ± 20                           | 93 ± 19                             | 0.424   |
| Peak SpO₂ (%)                           | 96 ± 3                            | 98 ± 2                              | 0.004†  |
| Peak Borg scale dyspnea                 | 5 [3–8]                           | 4.5 [3.5–8]                         | 0.698   |
| Peak Borg scale leg fatigue             | 7 [3.5–8]                         | 6 [3–8]                             | 0.766   |

Data are presented as mean ± standard deviation (SD); Student’s t-tests were used for group comparisons.
†Statistical significance set at p < 0.05.
Borg: Modified Borg scale (0-10) for rate of perceived exertion scale; FEV1: Forced expiratory volume after 1 second; FRC: Functional residual capacity; FVC: Forced vital capacity; RER: Respiratory exchange ratio; SpO₂: Pulse oximetry; TLC: Total lung capacity; VCO₂: Pulmonary carbon dioxide output; VE: Minute ventilation; VO₂: Oxygen uptake.

SpO₂ values compared with nonobese COVID-19 patients (Table 1). Amputated ventilatory reserve (<15%) and significant reduction (<3%) of SpO₂ values were more frequent in obese patients compared with nonobese patients (39.4% vs 11.1%, p = 0.032; 51.5% vs 16.7%, p = 0.015, respectively).

Descriptive characteristics for obese non-COVID patients are summarized in Table 2. Compared with obese non-COVID-19 patients, obese COVID-19 patients displayed exaggerated ventilatory drive, reduced ventilatory reserve, reduced O₂ pulse and lower SpO₂ values, with similar impairment of aerobic capacity (Table 2).

Discussion
More than half of nonsevere hospitalized COVID-19 patients diagnosed with chronic post-COVID-19 displayed reduced aerobic capacity 6 months after hospital discharge in the current research. Despite similar VO₂peak impairment compared with nonobese chronic post-COVID-19 patients, obese chronic post-COVID-19 patients displayed exaggerated hyperventilation as evidenced by increased ventilatory equivalent for oxygen (VE/VO₂ ratio) and VĖ/VCO₂ slope along with abnormal pulmonary gas exchange at peak exercise. Functional lung tests
of chronic post-COVID-19 patients were consistent with previous studies showing a reduction of lung volumes and impaired diffusion capacity for carbon monoxide (DLCO) along with lung transfer coefficient for carbon monoxide (KCO) above the upper limit of normal [19]. Recent insightful comments have suggested that the contrasting diffusion capacity and transfer coefficient changes may be the result of reduced alveolar volume, residual interstitial abnormalities and pulmonary vascular abnormalities [20].

These results are also consistent with previous studies showing that one-third of nonsevere COVID-19 survivors have a significant alteration in VO2peak after hospital discharge [15]. The present results highlight the deleterious impacts of obesity on ventilatory response and gas exchange at exercise in chronic post-COVID-19 patients. Indeed, the behavior of the pulmonary response at peak exercise in obese chronic post-COVID-19 patients was characterized by hyperventilation with amputated ventilatory reserve, along with significant fall in SpO2, which are all dysfunctional breathing responses to exercise and impairment of gas exchange. Exertional oxygen desaturation (SpO2) is an interesting finding that should be considered in rehabilitation programs for chronic post-COVID-19 in obese patients.

Despite similar aerobic capacity impairment, obese chronic post-COVID-19 patients had lower O2 pulse compared with obese non-COVID-19 patients, which suggests that extrapulmonary factors, especially cardiac dysfunction, may be considered in patients with chronic post-COVID-19. Hence, pulmonary dysfunction and gas transfer inefficiency may not be the sole reason for the abnormal exercise response in obese patients with chronic post-COVID-19, as reduced O2 pulse (a noninvasive surrogate of left ventricle stroke volume) indicated poor myocardial function. These findings should be integrated into the rehabilitation programs for these patients, particularly those who are overweight or obese.

Study limitations
First, this observational study conducted at the University Hospital of Martinique is monocentric and retrospective. Second, cardiopulmonary exercise testing was performed on patients able to cycle and without contraindications such as unstable cardiovascular diseases, orthopedic impairment and mental impairment leading to inability to cooperate. Also, the high proportion of chronic post-COVID-19 patients displaying aerobic capacity impairment may be related to the preferential selection of CPET for patients with the more severe form of chronic post-COVID syndrome. Overall fitness status or physical activity of COVID-19 and non-COVID-19 patients were not evaluated as potential confounding factors for peak levels of VO2. Moreover, only patients with mild COVID-19 disease were studied and no further follow-up was performed. While displaying similar comorbidities, obese non-COVID-19 patients undergoing bariatric surgery were younger, mostly female and had higher BMI, making them a fairly weak comparison group for obese chronic post-COVID-19 patients.

Conclusion
It has been previously shown that individuals with obesity may have an increased risk of hospitalization and death from acute COVID-19. Individuals with obesity may have a greater risk of hospital admission for chronic post-COVID-19 syndrome. This study was designed to better characterize the pulmonary, cardiac and functional capacity of SARS-CoV-2 survivors at 6 months by performing cardiopulmonary exercise testing. Six months after recovery from COVID-19, many patients are still affected by reduced maximal exercise capacity. Analysis of main CPET characteristics suggested that obese COVID-19 patients displayed exaggerated ventilatory drive, reduced ventilatory reserve and lower SpO2 values while having similar impairment of aerobic capacity. Thus, obese patients with long COVID-19 conditions should be considered at risk in exercise rehabilitation due to dysfunctional breathing response and impaired efficiency of pulmonary gas exchange.

Summary points
- Patients with chronic post-COVID-19 syndrome displayed abnormal cardiopulmonary response to exercise 6 months after hospital discharge that was characterized by impaired maximal aerobic capacity.
- Compared with normal-weight patients with chronic post-COVID-19 syndrome, patients who were overweight or obese displayed exaggerated hyperventilation as evidenced by increased ventilatory equivalent for oxygen (Ve/VO2 ratio) and Ve/VECO2 slope, along with abnormal pulmonary gas exchange at peak.
- Compared with non-COVID-19 obese patients, chronic post-COVID-19 patients who were overweight or obese also demonstrated reduced oxygen pulse (a noninvasive surrogate of left ventricle stroke volume), which may suggest poor myocardial function.
Author contributions
MR Lacavalerie, S Pierre-Francois, JL Barnay and M Agossou were involved in data collection and data analysis. A Cabie, J Inamo and R Neviere were involved in the study design, data analysis, data interpretation, literature search and writing of the manuscript. All authors were involved in writing the paper and had final approval of the submitted versions.

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Ethical conduct of research
Our manuscript includes a statement on ethics approval and consent and the name of the ethics committee that approved the study and the committee’s reference number. The study was conducted in accordance with the amended Declaration of Helsinki (http://www.wma.net/en/30publications/10policies/b3/). Written informed consent was obtained from all patients. The local Institutional Review Board approved this study (University Hospital of Martinique; reference number 2020/048).

Availability of data
The data that support the findings of this study are available but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission.

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