Effect of Surgical Masks on Cardiopulmonary Function in Healthy Young Subjects: A Crossover Study

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Objective: Mask plays an important role in preventing infectious respiratory diseases. The influence of wearing masks in physical exercise on the human body needs to be studied. The purpose of this study is to explore the influence of wearing surgical masks on the cardiopulmonary function of healthy people during exercise.

Methods: The physiological responses of 71 healthy subjects (35 men and 36 women, age 27.77 ± 7.76 years) to exercises with and without surgical masks (mask-on and mask-off) were analyzed. Cardiopulmonary function and metabolic reaction were measured by the cardiopulmonary exercise test (CPET). All tests were carried out in random sequence and should be completed in 1 week.

Results: The CPETs with the mask-on condition were performed undesirably (p < 0.05), and the Borg scale was higher than the mask-off (p < 0.001). Rest oxygen uptake (VO2) and carbon dioxide production (VCO2) with the mask-on condition were lower than mask-off (p < 0.01), which were more obvious at peak exercise (VO2peak: 1454.8 ± 418.9 vs. 1628.6 ± 447.2 ml/min, p < 0.001; VCO2peak: 1873.0 ± 578.7 vs. 2169.9 ± 627.8 ml/min, p = 0.005), and the anaerobic threshold (AT) brought forward (p < 0.001). At different stages of CPET with the mask-on condition, inspiratory and expiratory time (Te) was longer (p < 0.05), and respiratory frequency (Rf) and minute ventilation (VE) were shorter than mask-off, especially at peak exercise (Rfpeak: 33.8 ± 7.98 vs. 37.91 ± 6.72 b/min, p < 0.001; VEpark: 55.07 ± 17.28 vs. 66.46 ± 17.93 l/min, p < 0.001). VT was significantly lower than mask-off just at peak exercise (1.66 ± 0.45 vs. 1.79 ± 0.5 l, p < 0.001). End-tidal oxygen partial pressure (PetO2), end-tidal carbon dioxide partial pressure (PetCO2), oxygen ventilation equivalent (VE/VO2), and carbon dioxide ventilation equivalent (VE/VCO2) with mask-on, which reflected pulmonary ventilation efficiency, were significantly different from mask-off at different stages of CPET (p < 0.05), but no significant difference in percutaneous oxygen saturation (SpO2) was found. Differences in oxygen pulse (VO2/HR), oxygen uptake efficiency slope (OUES), work efficiency (ΔVO2/ΔW), peak heart rate (HR), and peak systolic blood pressure (BP) existed between two conditions (p < 0.05).
demonstrated that after wearing masks, the maximum oxygen uptake (\( \dot{V}O_2 \)) and ventilation decreased, and 11 athletes had acute dyspnea at the peak of maximal exercise test (Egger et al., 2021). Athletes with good cardiopulmonary reserve function had such changes, not to mention ordinary healthy people. Fikenzer et al. (2020) conducted cardiopulmonary exercise tests (CPETs) on 12 healthy men under different masks. The results showed that surgical masks and FFP2/N95 masks could reduce ventilation, exercise endurance, and comfort. Lässing et al. (2020) tested 14 healthy men with constant power exercise and found out that the peak heart rate (HR) and cardiac output (CO) were larger when wearing surgical masks, but there were no differences in the changes in blood pressure (BP) and blood lactate. However, the research of Shaw K demonstrated that wearing masks for strenuous exercise had no obvious effect on the exercise performance of healthy young people, such as percutaneous oxygen saturation (SpO2), tissue oxygenation index, exercise maximum load, exercise HR, and rating of perceived exertion (RPE) (Shaw et al., 2020). A study on sarcopenia patients also showed that when wearing surgical or FFP2 masks for resistance training the changes in HR, HR variability, blood lactic acid concentration, self-perceived fatigue, and muscle strength were similar with not wearing masks (Ramos-Campo et al., 2021).

The influence of masks on human cardiopulmonary function during exercise remains unclear, and proper exercise training is an effective measure to prevent diseases and improve the prognosis of diseases. In the ongoing epidemic, people still need to wear masks for a long time, so it is necessary to further study the influence of wearing masks on human cardiopulmonary function. Therefore, this study intends to explore the effect of surgical masks in healthy people by monitoring the changes in cardiopulmonary function and metabolic parameters to guide safe exercise while wearing surgical masks.

**MATERIALS AND METHODS**

**Subjects**

The research is a self-controlled trial, which has been approved by the Ethics Committee of Guangdong Provincial People’s Hospital (ethics number: GDREC2020145H) and can be consulted in the Chinese Clinical trial registry (No. ChiCTR2000033449). Healthy subjects were recruited from June 1, 2020 to July 31, 2020. The inclusion criteria of the study included subjects between 18 and 40 years old, who participated voluntarily, passed PAR-Q questionnaire screening, had normal rest electrocardiogram and static lung function, and had signed informed consent. The presence of any of the following conditions would not be
allowed to participate in the study, including the history of COVID-19 infection, previous cardiopulmonary diseases (such as asthma, chronic bronchitis, pulmonary fibrosis, emphysema, and congenital heart disease), situations (such as exercise asthma and epilepsy) that may deteriorate due to exercise, physical disability caused by articularizations or neuromuscular diseases, lower respiratory tract infection in the past 2 weeks, acute upper respiratory tract infection or symptomatic rhinitis in the past 1 week, mental or cognitive disabilities, smoking, pregnancy, menstrual period and lactation period, and other contraindications of CPET.

Study Design
Every subject was asked to go to the hospital to complete the CPET two times. The two tests were carried out under conditions A (mask-on) and B (mask-off). The interval between the two tests was at least 24 h and completed within 1 week. Every subject was randomly assigned to CPET according to AB sequence or BA sequence (flow chart is as Figure 1). All CPETs were completed by one professional. When subjects entered the experiment, medical data were collected, and vital signs, height, weight, rest electrocardiogram, and static lung function tests were carried out by special personnel.

Masks
All subjects were provided with typical and widely used disposable ear-hanging surgical masks for adults (Guangzhou Tianhe Haozheng Sanitary Materials Factory, Guangzhou, China). The spirometry mask (V2 MASK, United States) used in CPET was selected according to the face shape of subjects and required to wear comfortably. The spirometry mask was placed over the surgical masks and fixed with head straps in a leak-proof manner (Figure 2). Before each CPET, an air leakage test was conducted to confirm whether the mask fits correctly. The tester completely blocked the ventilation valve of the spirometry mask with the palm of the hand. Then, the subjects breathed with maximal force against the mask to check for leaks (Figure 2). This maneuver was repeated until no acoustic, visual, and sensory indications of leakage were detectable.

Testing Equipment
Cardiopulmonary Exercise Test
The CPET was performed with JAEGER Master Screen CPX (Germany) system and the cycle ergometer (Ergoline 150P, Germany). Calibration of the gas analyzer was performed before each test, including flow sensor calibration, indoor air calibration, standard balance gas (using 16%O2, 5%CO2, and N2) calibration, and delay calibration. Subjects were asked to take more than 2 h after eating without satiety, were advised to avoid eating foods containing caffeine and alcohol at least 12 h before the test, and were ensured to take adequate rest the day before the test.

Cardiopulmonary Exercise Test Protocol
The CPETs were performed using a ramped cycle ergometer protocol, and incremental power was calculated to let subjects finish the exercise load test in 8–12 min. The incremental power selection was calculated with the following formulas (Costa et al., 2015):

\[
\dot{V}O_2 \text{(ml/min) without load} = 150 + (6 \times \text{body weight kg})
\]

\[
\dot{V}O_2\text{max (ml/min)} = (\text{height cm} - \text{age Y}) \times 20 \text{ (male),}
\]

\[
\dot{V}O_2\text{max (ml/min)} = (\text{height cm} - \text{age Y}) \times 14 \text{ (female)}
\]

\[
\text{Incremental power per minute} = (\dot{V}O_2\text{max} - \dot{V}O_2\text{without load})/100.
\]

Specific Process
First, the forced vital capacity (FVC), forced expiratory volume in one second (FEV1), FEV1/FVC, and maximum minute ventilation (MVV) were measured. Then, while the subject was wearing a spirometry mask connected with a gas analyzer, a 12-leads ECG was connected, BP cuff and fingertip oxyhemoglobin saturation meter were adjusted, and the seat height of the cycle ergometer was set. Next, the subjects rested for 2 min in a sitting position, collecting rest real-time gas metabolism and ECG data. After 2-min warming up with 0 W, the subjects pedaled the cycle according to the set incremental power (15–25 W/min) until exhaustion, and the pedaling speed was kept at about 60 RPM. The test system automatically collected real-time gas metabolism data through the gas analyzer, ECG, and BP data through telemetry cardiogram monitor, and automatically calculated average values every 10 s of parameters that reflect metabolism, gas exchange, ventilation efficiency, and cardiovascular function, according to the oxygen concentration, carbon dioxide concentration, and respiratory flow rate measured breath-by-breath. When the subjects reached the best effort standard (Dougherty et al., 2018), which met at least three of the following items: (1) RPE ≥ 17; (2) respiratory exchange rate (RER) ≥ 1.10; (3) HRpeak reaches more than 90% of the predicted maximum HR; (4) VO2 increases <200 ml (as increased power) or reached other criteria for terminating exercise test, the subjects pedaled for 3 min at 0 W, resting in the sitting position for 3 min to finish the test.

Criteria for Terminating the Exercise Test
The test can be terminated when any of the following items are met:

1. Pedal to exhaustion (RPE ≥ 17–18), the pedaling speed cannot be maintained, lower than 40 RPM.
2. Clinical symptoms: fatigue or dyspnea, severe chest pain; systolic BP decreased by 10 mmHg; cerebral ischemic symptoms, such as dizziness and headache; poor peripheral circulation, such as the face is pale and BP cannot be measured; the subject asked to stop strongly.
3. ECG changes: exercise-induced ST-segment depression ≥ 3 mm or ST-segment elevation > 1 mm;
HR did not increase but decreased as exercise intensity increased; the ECG axis was extremely offset; ventricular tachycardia; supraventricular tachycardia; frequent ventricular extrasystoles caused or aggravated by exercise; indoor conduction block caused by exercise.

4. Metabolic index: RER was above 1.15; SpO₂ dropped below 86%, and respiratory rate was more than 50 beats/min. Oxygen pulse and VO₂ appeared to plateau or decrease. HR reserve (HRR) and breathing reserve (BR%) were exhausted.
Rating of Perceived Exertion and Borg Dyspnea Scale

After each CPET, the subjects were asked about the degree of discomfort or intolerance using RPE and Borg dyspnea scale. RPE was scored from 6 to 20, indicating extremely light to exhaustion. Borg dyspnea scale was from 0 to 10, indicating no dyspnea at all to extremely severe dyspnea.

Outcomes

This study obtained data of the following parameters:

1. CPET performance: CPET test duration, maximum power, RPE score, and Borg dyspnea scale.
2. Parameters reflecting metabolism: \( \dot{V}O_2 \), carbon dioxide production (\( \dot{V}CO_2 \)), metabolic equivalent (MET), RER, and percentage of oxygen uptake at anaerobic threshold (AT) in predicted maximal oxygen uptake (\( \dot{V}O_2@AT/\dot{V}O_2^{\text{max}} \)) pre %. Among them, AT was determined by the V-slope method.
3. Parameters reflecting lung ventilation and ventilation efficiency: inspiratory time (Ti), expiratory time (Te), respiratory frequency (Rf), tidal volume (VT), minute ventilation volume (VE), end-tidal oxygen partial pressure (PetO2), end-tidal carbon dioxide partial pressure (PetCO2), oxygen ventilation equivalent (VE/VO2), and carbon dioxide ventilation equivalent (VE/CO2), carbon dioxide ventilation equivalent slope (VE/CO2 Slope), and BR% and SpO2.
4. Parameters reflecting cardiovascular function: oxygen pulse (\( \dot{V}O_2/HR \)), work efficiency (\( \Delta \dot{V}O_2/\Delta W \)), oxygen uptake efficiency slope (OUES), BP, HR, and HRR.

The main outcome measures were VE, VT, PetCO2, VE, VO2/kg, VO2/kg, VO2/HR, and OUES.

Sample Size Estimation

According to the pre-experiment results, the main outcome measure was \( \dot{V}O_2^{\text{peak}}/kg \), and the software G*Power 3.1.92 was used. The authors assumed that the risk was 0.05 and the risk was 0.95, the average difference of \( \dot{V}O_2^{\text{peak}}/kg \) between two groups of CPETs (with and without masks) was 11.7 (SD is 13.27) ml/min/kg. The results showed that 44 subjects were needed.
### Statistical Analysis

SPSS 25.0 statistical software was used for data processing. The measurement data were tested for normality, and the normal distribution data were expressed in mean ± SD (± s) and the non-normal distribution data was expressed in the median; enumeration data used cases and the rate (%). Paired t-test was used for self-comparison of normal distribution variables; the Wilcoxon rank-sum test was used for self-comparison of non-normal distribution variables. The significance level was set at \( p < 0.05 \).

### RESULTS

#### Baseline Characteristic

A total of 75 subjects were recruited, in which 4 subjects were excluded because 1 had influenza, 2 were menstruating, and 1 was under antidepressant. So, 71 healthy subjects (men 35, women 36) were recruited through outpatient service, with an average age of 27.77 ± 7.76 years and an average BMI of 21.46 ± 2.75 kg/m². Among them, 77% of subjects exercised less than three times per week and 1 h per day. The mean FVC, FEV₁, FEV₁/FVC, and MVV of subjects were 3.89 ± 0.78 l, 3.27 ± 0.60 l, 84.6 ± 6.72%, and 118.40 ± 30.10 l, respectively (Table 1).

#### Cardiopulmonary Exercise Test Performances

The CPET test time was slightly shorter in mask-on condition than mask-off (7.97 ± 1.50 vs. 8.20 ± 1.39 min, \( p = 0.052 \)), and the maximum power in mask-on condition was also significantly lower than mask-off (142.9 ± 44.22 vs. 149.8 ± 46.04 W, \( p < 0.001 \)). The RPE and the Borg scale of the two conditions were significantly different (\( p < 0.001 \)), and the Borg scales of the mask-on condition were higher (5.69 ± 1.62 vs. 4.78 ± 1.72, \( p < 0.001 \)) (Table 2).

### Metabolic Reaction Parameters

The results of metabolic reaction parameters showed that VO₂, VO₂/kg, and MET of mask-off and mask-on were significantly different in each stage of CPET (\( p < 0.001 \)), and VO₂peak and VO₂peak/kg of mask-on was significantly lower than mask-off (\( VO₂peak: 454.8 ± 418.9 \) vs. 1628.6 ± 447.2 ml/min, \( p < 0.001 \); \( VO₂peak/kg: 24.33 ± 4.96 \) vs. 27.3 ± 5.47 ml/min/kg, \( p < 0.001 \)). There were significant differences in both conditions on \( VO₂/AT/VO₂ \) max pre % (\( p < 0.001 \)). The VO₂ of mask-on was lower than mask-off in the rest period of CPET (209.7 ± 81.74 vs. 250.2 ± 94.14 ml/min, \( p = 0.007 \)), and the difference was more significant in the peak exercise period (1873.0 ± 578.7 vs. 2169.9 ± 627.8 ml/min, \( p = 0.005 \)). There were significant differences in both conditions on RER only at peak exercise (\( p < 0.001 \)) (Table 3).

### Lung Function Parameters

The results of lung ventilation response parameters showed that at different stages of CPET with mask-on condition, Ti and Te were longer than mask-off (\( p < 0.05 \)). The differences of Ti between mask-on and mask-off at rest, AT and peak period were 0.39 ± 0.76 s (\( p < 0.001 \)), 0.30 ± 0.37 s (\( p < 0.001 \)) and 0.20 ± 0.27 s (\( p < 0.001 \)), respectively. The differences of Te between mask-on and mask-off at rest, AT and peak period were 0.21 ± 0.64 s (\( p = 0.008 \)), 0.14 ± 0.47 s (\( p = 0.016 \)) and 0.05 ± 0.27 s (\( p = 0.164 \)), respectively (Figure 3).

Respiratory frequency and \( V_E \) of mask-on were lower than mask-off at each stage of CPET (\( p < 0.05 \)), especially at peak exercise (\( R_{peak} : 33.8 ± 7.98 \) vs. 37.91 ± 6.72 b/min, \( p < 0.001 \); \( V_{peak} : 55.07 ± 17.28 \) vs. 66.46 ± 17.93 l/min, \( p < 0.001 \)), and \( V_T \) was significantly lower than mask-off just at peak exercise (1.66 ± 0.45 vs. 1.79 ± 0.51 l, \( p < 0.001 \)). BR% of mask-on was higher than mask-off at all stages of CPET (\( p < 0.001 \)). There was no significant difference between mask-off and mask-on in \( S\text{PO}_2 \) (\( p > 0.05 \)) (Table 4).

The result of pulmonary ventilation efficiency parameters showed that there were no significant differences in \( P_{ET} \) and \( V_{E/VO}_2 \) between mask-off and mask-on during the rest period (\( p > 0.05 \)), but \( PET_2 \) and \( V_{E/VO}_2 \) of mask-on during warm-up period to peak exercise period were lower than mask-off (\( p < 0.05 \)). At all stages of CPET, \( PET\Delta CO_2 \) of mask-on was higher than mask-off and \( V_{E/VO}_2 \) was lower than mask-off (\( p < 0.05 \)), but there was no significant difference in \( V_{E/VO}_2 \) slope between them (\( p > 0.05 \)) (Table 4).

### Cardiovascular Reaction Parameters

The result of cardiovascular response parameters showed that \( VO_{2}/HR \), OUES, and \( \Delta VO_{2}/\Delta W \) of mask-on was significantly lower than mask-off (\( VO_{2peak}/HR: 8.82 ± 2.6 \) vs. 9.51 ± 2.48 ml/beat, \( p < 0.001 \); OUES: 1641.2 ± 449.5 vs. 1914.4 ± 498.3 ml/min/l/min, \( p < 0.001 \); \( \Delta VO_{2}/\Delta W: 8.04 ± 1.03 \) vs. 8.55 ± 0.9 mlO₂/W, \( p = 0.002 \)), while HR, HRR, and systolic BP were significantly different at peak exercise (\( p < 0.05 \)), and

### Table 1 | Baseline characteristics.

| Items                  | Unit | Mean ± SD      |
|------------------------|------|----------------|
| Age                    | Years| 27.8 ± 7.76    |
| Gender                 |      |                |
| Male                   |      | 35             |
| Female                 |      | 36             |
| Weight                 | kg   | 59.6 ± 10.6    |
| Height                 | cm   | 166.3 ± 8.50   |
| BMI                    | kg/m²| 21.5 ± 2.75    |
| Exercise frequency     |      |                |
| Number of subjects (>3 times/week, 1 h/day) | 16 |   |
| Number of subjects (<3 times/week, 1 h/day) | 55 |   |
| Static lung function   |      |                |
| FVC                    | l    | 3.89 ± 0.78    |
| FEV₁                   | l    | 3.27 ± 0.60    |
| FEV₁/FVC               | %    | 84.6 ± 6.72    |
| MVV                    | l/min| 118.4 ± 30.1   |

BMI: body mass index; FVC: forced vital capacity; FEV₁: forced capacity volume in the first second; MVV: maximal voluntary ventilation; kg: kilogram; cm: centimeter; m: meter; min: minute; l: liter; SD: standard deviation.
The result demonstrated that the mask had significant effects on healthy people under exercise load through self-comparison. (Dharmadhikari et al., 2012; Chu et al., 2020). This study selected and the role of the mask in COVID-19 has been confirmed.

**DISCUSSION**

First, surgical masks influenced the performance in CPET. This research suggested that the exercise test time and a maximum power of healthy subjects wearing masks were lower than those without masks, and the dyspnea index was increased. In the study on 31 adults (Driver et al., 2021) cloth face masks led to a 14% reduction in exercise time and attributed to perceived discomfort (such as feeling increasingly short of breath and claustrophobic at higher exercise intensities) associated with mask-wearing. Therefore, masks could affect the exercise performance and subjective feelings of healthy subjects.

Second, surgical masks had influences on lung function. Both this study and Mapelli’s (Mapelli et al., 2021) study found out that after wearing masks, Ti and Te increased since rest period, especially Ti, which indirectly reflected that masks could increase the inspiratory and expiratory resistance of the oronasal airway. The increase of facial temperature and humidity during exercise could also cause moisture and deformation of the mask, which could further increase respiratory resistance. Different types of masks cause different respiratory resistance, which led to the greater the respiratory resistance, the larger the dead space, and the greater the influence on the ventilation function and ventilation efficiency (Jones et al., 1971). Studies had shown that after wearing N95 filter masks, the inspiratory and expiratory resistance increased by 0.43 and 0.23 mmH2O, respectively (Roberge et al., 2010a). An animal study measured the maximum speed of six horses in the treadmill exercise test, and then exercised on the treadmill at the maximum speeds of 50, 75, and 100%, respectively with and without masks. The results showed that compared with those without masks, the difference of peak inspiratory pressure between trachea and pharynx increased negatively, peak expiratory pressure between trachea and pharynx increased positively, and Rf was lower (p < 0.05) (Holcombe et al., 1996). The increase of respiratory resistance prolonged the breathing time to meet the ventilation needs, which led to the slowdown of Rf after wearing a mask. Meanwhile, the increase of respiratory resistance and the slowdown of Rf led to the decrease of VT, showing insufficient ventilation, resulting in the decrease of VE and the increase of BR%. This study confirmed that Rf, VT, and VE decreased and BR% increased after wearing surgical masks, especially in the peak period of exercise. Seo et al. (2017) tested nine healthy men wearing masks with different inspiratory resistances, and the results also showed that Rf and VE decreased with the increase of inspiratory resistance.

However, Roberge et al. studies20 healthy adult subjects walking...
on a flat plate at a speed of 5.6 km/h for 1 h with or without wearing surgical masks, and the results showed that wearing masks caused an increase in RF by 1.6 beats/min ($p = 0.02$) (Roberge et al., 2012). It was also observed that the subjects walked at the same speed for 1 h while wearing N95 masks, and the RF of the mask group increased by 1.4–2.4 beats/min ($p < 0.05$) compared with the control group (Kim et al., 2013). The exercise method used in these two studies was to walk on a flat plate at a constant speed, with limb muscles and even chest muscles participating in the exercise for a longer period. However, this study used cycle ergometer incremental exercise, with mainly lower limb muscles participating for a shorter time, and the inhaled oxygen concentration decreased, which led to the exercise intensity increased. As inspiratory resistance increased, the expiratory time could be decreased by 12–31% with the increase of inspiratory resistance (Caretti and Whitley, 1998). In addition, the expiratory resistance might cause compensatory acceleration of RF (Qiu and Wang, 2012). According to the results of this study, the respiratory pattern change caused by wearing surgical masks was insufficient ventilation, which affected the ventilation function.

The increase of respiratory resistance after wearing masks would increase the work done by respiratory muscles and affected the gas exchange and ventilation efficiency. In this study, $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}E/\dot{V}O_2$, and $\dot{V}E/\dot{V}CO_2$ all decreased and PetCO$_2$ increased after wearing surgical masks. The changes existed in the rest period or warm-up exercise and became more significant as exercise intensity increased. As inspiratory resistance increased, the inhaled oxygen concentration decreased, which led to the decrease of $\dot{V}O_2$ and PetO$_2$. $\dot{V}E$ decreased more significantly than $\dot{V}O_2$, so $\dot{V}E/\dot{V}O_2$ decreased. The study showed that $\dot{V}E/\dot{V}O_2$ could be decreased by 12–31% with the increase of inspiratory resistance (Caretti and Whitley, 1998). In addition, the expiratory resistance increased and the dead space increased, resulting in a decrease in $\dot{V}CO_2$ and a higher PaCO$_2$, showing a relative carbon dioxide retention performance (Holcombe et al., 1996). Umutlu et al. (2021) also indicated that $\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}E$ decreased significantly during aerobic exercise ($p < 0.001$). Because $\dot{V}E$ decreased more significantly than $\dot{V}CO_2$, so the decrease in $\dot{V}E/\dot{V}CO_2$ was well proved in this study. However, due to the limited discharge of carbon dioxide, the concentration of carbon dioxide in the mask and inhaled increased (Roberge et al., 2012; Smith et al., 2013). Therefore, this study observed that PetCO$_2$ was higher when wearing surgical masks than mask-off ($p < 0.001$). Roberge et al. (2012) also found out that after wearing masks, the percutaneous carbon dioxide partial pressure increased by 2.17 mmHg ($P = 0.0006$), and a similar change existed when exercising with N95 mask (Kim et al., 2013; Goh et al., 2019). Epstein et al. (2021) found PetCO$_2$ increased with the increase of exercise load after wearing N95 masks, and it increased by 8 mmHg at peak exercise. It could be seen that wearing masks presented pathophysiological changes similar to COPD, which would reduce ventilation efficiency, especially during high-intensity exercise. In this study, no hypoxemia occurred in healthy subjects, which was related to the strong compensatory ability of healthy people. However, for patients with respiratory diseases, such as COPD or heart failure, the above physiological changes might aggravate the condition of the patient (Hopkins et al., 2021). Therefore, such patients were required to be fully evaluated before exercising with masks.

Third, surgical masks influenced cardiopulmonary fitness and exercise endurance. Cardiopulmonary fitness has been listed as the fifth vital sign by AHA, which not only reflected exercise endurance but also was an effective index for disease occurrence risk and death risk (Ross et al., 2016). Maximum $\dot{V}O_2$ was often used to evaluate cardiopulmonary fitness. The walking test (6 min) was a simple and easy method to evaluate cardiopulmonary fitness and exercise endurance. Person et al. (2018) randomly divided 44 healthy people into a mask-on and a mask-off group and conducted a 6 min walking test, respectively. The results showed that the 6 min walk distance, HR, and SpO$_2$ did not change significantly, and only the dyspnea index increased significantly. The 6 min walking test was a kind of sub-maximal exercise test, which was not accurate enough.
The values were shown in mean ± standard deviation. Significance level was set at  \( P < 0.05 \). \( V_E \), minute ventilation; \( V_T \), tidal volume; BR, breathing reserve; RF, breathing frequency; \( \text{SpO}_2 \), percutaneous oxygen saturation; \( \text{PetO}_2 \), end-tidal oxygen partial pressure; \( \text{PetCO}_2 \), end-tidal carbon dioxide partial pressure; \( \text{VCO}_2 \), carbon dioxide production; \( \text{VCO}_2 \), carbon dioxide output; AT, anaerobic threshold. Significant results are indicated in bold.

| Parameter          | Mask-off       | Mask-on        | Cohen’s d effect size | \( P \) value |
|--------------------|----------------|----------------|-----------------------|--------------|
| \( V_E \) (l/min)  |                |                |                       |              |
| Rest               | 10.7 ± 3.07    | 8.84 ± 2.94    | 0.62                  | <0.001       |
| Warm up            | 15.8 ± 2.70    | 13.1 ± 3.64    | 0.82                  | <0.001       |
| AT                 | 29.5 ± 6.56    | 25.8 ± 8.13    | 0.50                  | <0.001       |
| Peak               | 66.5 ± 17.9    | 55.1 ± 17.3    | 0.65                  | <0.001       |
| \( V_T \) (l)      |                |                |                       |              |
| Rest               | 0.59 ± 0.20    | 0.57 ± 0.27    | 0.08                  | 0.083        |
| Warm up            | 0.79 ± 0.28    | 0.74 ± 0.37    | 0.15                  | 0.017        |
| AT                 | 1.28 ± 0.41    | 1.27 ± 0.49    | 0.02                  | 0.388        |
| Peak               | 1.79 ± 0.50    | 1.66 ± 0.45    | 0.27                  | <0.001       |
| BR (%)             |                |                |                       |              |
| Rest               | 91.3 ± 2.26    | 92.8 ± 2.37    | 0.64                  | <0.001       |
| Warm up            | 87.3 ± 2.64    | 89.4 ± 2.87    | 0.76                  | <0.001       |
| AT                 | 76.7 ± 5.02    | 79.7 ± 5.43    | 0.58                  | <0.001       |
| Peak               | 48.4 ± 10.9    | 57.0 ± 11.3    | 0.77                  | <0.001       |
| \( \text{SpO}_2 \) % |                |                |                       |              |
| Rest               | 94.9 ± 20.6    | 97.9 ± 12.1    | 0.17                  | 0.161        |
| Warm up            | 95.8 ± 17.0    | 97.5 ± 12.2    | 0.11                  | 0.144        |
| AT                 | 96.9 ± 12.3    | 96.8 ± 8.51    | 0.01                  | 0.094        |
| Peak               | 95.3 ± 8.72    | 95.3 ± 9.25    | 0.001                 | 0.564        |
| \( \text{PetO}_2 \) (mmHg) |            |                |                       |              |
| Rest               | 108.9 ± 10.9   | 106.9 ± 6.09   | 0.005                 | 0.266        |
| Warm up            | 107.6 ± 9.68   | 105.1 ± 11.0   | 0.24                  | <0.001       |
| AT                 | 105.1 ± 8.59   | 103.2 ± 9.38   | 0.21                  | 0.002        |
| Peak               | 115.7 ± 9.75   | 112.2 ± 11.0   | 0.33                  | <0.001       |
| \( \text{PetCO}_2 \) (mmHg) |            |                |                       |              |
| Rest               | 34.2 ± 10.3    | 34.9 ± 8.03    | 0.08                  | 0.040        |
| Warm up            | 36.5 ± 8.85    | 37.4 ± 9.64    | 0.10                  | 0.027        |
| AT                 | 42.2 ± 7.86    | 43.6 ± 8.40    | 0.17                  | 0.001        |
| Peak               | 38.8 ± 9.70    | 41.6 ± 10.2    | 0.28                  | <0.001       |
| \( V_E/\text{VO}_2 \) |            |                |                       |              |
| Rest               | 33.2 ± 5.49    | 32.6 ± 6.16    | 0.11                  | 0.350        |
| Warm up            | 30.3 ± 3.67    | 28.2 ± 4.93    | 0.47                  | <0.001       |
| AT                 | 27.4 ± 3.38    | 26.2 ± 4.04    | 0.33                  | 0.001        |
| Peak               | 39.6 ± 5.80    | 36.4 ± 6.82    | 0.51                  | <0.001       |
| \( V_E/\text{VCO}_2 \) |            |                |                       |              |
| Rest               | 38.8 ± 6.17    | 37.4 ± 7.24    | 0.21                  | 0.049        |
| Warm up            | 34.5 ± 4.46    | 32.6 ± 5.86    | 0.36                  | <0.001       |
| AT                 | 27.9 ± 3.34    | 26.9 ± 4.04    | 0.27                  | 0.002        |
| Peak               | 30.3 ± 3.87    | 28.8 ± 4.68    | 0.34                  | <0.001       |
| \( V_E/\text{VCO}_2 \) slope |    | 26.4 ± 3.38    | 26.0 ± 4.49 | 0.08 | 0.512    |

to fully reflect the cardiopulmonary function and metabolism, however, CPET was more accurate. Through CPET, this study found out that \( \text{VO}_2 \) had decreased since the rest period, and \( \text{VO}_2\text{peak} \) was decreased by about 11% (\( p < 0.001 \)). After wearing FFP2/N95 mask, \( \text{VO}_2\text{peak} \) could decrease by 13% (Fikenzer et al., 2020). In the study of Driver et al., cloth face masks led to a 29% decrease in \( \text{VO}_2\text{max} \) (\( p < 0.001 \)) (Driver et al., 2021). Dressendorfer et al. (1977) showed that \( \text{VO}_2\text{peak} \) after wearing...
The values were shown in mean ± standard deviation. Significance level was set at $P < 0.05$. HR, heart rate; HRR, heart rate reserve; $\dot{V}$O$_2$, oxygen uptake; Payst, systolic pressure; Pdiast, diastolic pressure; OUES, oxygen uptake efficiency slope; AT, anaerobic threshold. Significant results are indicated in bold.

|                                | Mask-off | Mask-on | Cohen's $d$ effect size | $P$ value |
|--------------------------------|----------|---------|-------------------------|-----------|
| HR (bpm)                       | 82.6 ± 11.5 | 82.0 ± 9.38 | 0.05 | 0.691 |
| AT                             | 127.8 ± 15.3 | 126.7 ± 16.2 | 0.13 | 0.557 |
| Peak                           | 171.0 ± 13.7 | 165.8 ± 15.7 | 0.35 | <0.001 |
| HRR (bpm)                      | 22.0 ± 12.9 | 26.2 ± 14.2 | 0.31 | 0.006 |
| $\dot{V}$O$_2$/HR (ml/beat)    | 3.56 ± 1.42 | 2.96 ± 1.18 | 0.48 | <0.001 |
| Payst (mmHg)                   | 104.3 ± 26.2 | 109.2 ± 15.5 | 0.21 | 0.561 |
| Pdiast (mmHg)                  | 66.1 ± 18.1 | 72.2 ± 11.4 | 0.25 | 0.130 |
| OUES (ml/ml/l/min)             | 1914.4 ± 498.3 | 1641.2 ± 449.5 | 0.57 | <0.001 |
| $\dot{V}$O$_2$/W (mlO$_2$/Watt) | 8.55 ± 0.90 | 8.04 ± 1.03 | 0.52 | 0.002 |

Surgical masks influence cardiovascular function. In general, the blood flow is redistributed during exercise, and the blood flow of the myocardium increased to ensure the blood pumping function of the heart. The excitation of the sympathetic nerve led to the enhancement of cardiac systolic function, the increase of stroke volume (SV), HR, CO, and BP. After wearing masks, the airway resistance increased, the negative pressure of the chest increased when inhaling, and the blood flow increased as well, increasing cardiac preload (Cooke et al., 2006). On the other hand, the contraction of peripheral vessels and the increase of cardiac afterload during exercise could cause the compensatory increase of SV, HR, and CO, and at the same time increased the extra work of the heart, which led to the decrease of work efficiency and oxygen utilization capacity of the heart (Cheyne et al., 2020). Umutlu et al. (2021) conducted CPET and walk test on 14 sedentary volunteers (all on a treadmill), showing that HR systolic BP and diastolic BP increased significantly after wearing masks ($p < 0.01$). Lässing et al. (2020) studied the changes in cardiopulmonary function during constant power test with surgical masks and found that HR$_{peak}$ increased significantly ($p < 0.01$), SV and CO increased slightly ($p > 0.05$), and arteriovenous oxygen difference (avDO$_2$) decreased significantly ($p = 0.02$). This study suggested that the decrease of $\dot{V}$O$_2$ after wearing masks was mainly related to the decrease of avDO$_2$ ($\dot{V}$O$_2 = CO \times$ avDO$_2$), while the change of lung function caused by wearing a mask could lead to the decrease of avDO$_2$; thus, the decrease of $\dot{V}$O$_2$ was mainly related to the change of lung function. However, Fikenzger et al. (2020) adopted the step-by-step incremental protocol for CPET. The results showed that the HR$_{peak}$ of exercise decreased when wearing surgical masks and FFP2/N95 masks, but it was more significant when wearing surgical masks ($p < 0.05$), and the SV and CO were slightly higher than those without masks ($p > 0.05$). Similarly, in this study, the HR$_{peak}$ of healthy volunteers decreased when exercising with surgical masks ($p < 0.05$), which might be related to the different CPET protocols and the short exercise time of...
CPET. There might be an obvious compensatory increase in HR for long-term high-intensity exercise, which needed further study. In addition, surgical masks led to a significant decrease in VO₂/HR, OUES (ratio of VO₂ to the logarithm of ventilation volume), and ΔVO₂/ΔW in this study, which was mainly related to the decrease of VO₂, indicating that wearing masks caused the decrease of oxygen transport capacity of heart and oxygen utilization capacity of the body in healthy people.

To summarize, surgical masks had a certain influence on the heart function of healthy people during exercise, which was mainly due to the limitation of lung function. For patients with heart diseases, this influence might be enlarged due to the damage of heart compensatory function.

Limitations
First, all the subjects included in this study were healthy people of low age, and the results could not reflect the influence of surgical masks on exercise cardiopulmonary function of middle-aged and elderly people and patients with cardiopulmonary disease. Second, this study did not combine blood gas analysis to accurately evaluate metabolism, which could more effectively reflect aerobic and anaerobic metabolism in vivo by measuring arterial oxygen partial pressure, carbon dioxide partial pressure, and lactic acid value.

CONCLUSION
Wearing surgical masks during aerobic exercise showed certain negative impacts on cardiopulmonary function, especially during high-intensity exercise in healthy young subjects. These results provide an important recommendation for wearing a mask at a pandemic during exercises of varying intensity. Future research should focus on the response of wearing masks in patients with related cardiopulmonary diseases.

DATA AVAILABILITY STATEMENT
The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

ETHICS STATEMENT
The studies involving human participants were reviewed and approved by the Research Ethics Committee Guangdong Provincial People’s Hospital, Guangdong Academy of Medical Sciences. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS
GZ and ML assisted in the subject recruitment, data collection, data analysis, and writing. MZ, XC, JY, SZ, and AY assisted with the data collection and data analysis. YZ, QL, and JL assisted with the data analysis. LG and HO assisted with the study design, data analysis, and manuscript editing. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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