A Portable Ventilator That Patients with COPD Can Use Outdoors

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A thesis presented in partial fulfillment of the requirements for a Master in Design at Massey University, Wellington, New Zealand

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Preface

My grandfather suffered from severe Chronic obstructive pulmonary disease (COPD), a disease that contributed to shortening his life and quality of life he experienced in his latter years. I took care of him for five months in 2023, tending to his daily needs and supporting his wellbeing. I am well aware of the mobility limitations of traditional ventilators for COPD patients, and the impacts COPD has, on physical and psychological health.

This study is dedicated to my grandfather - Zhu Dianjie

Abstract

Chronic obstructive pulmonary disease (COPD) is a chronic inflammatory lung disease characterized by airflow limitation, severely affecting patients' respiratory function and quality of life. Patients who are long-term dependent on mechanical ventilation often face additional health risks due to sedentary behavior. This study analysis's the components and structure of ventilator products to gain insights and understandings to advance mobile ventilator design. This product concept investigations aims to meet treatment requirements, enhancing the daily lives and mobility of patients. This design research opens new possibilities for the improvement of medical equipment and aims to meet treatment requirements without affecting patients' daily lives.

Introduction

Chronic Obstructive Pulmonary Disease(COPD), is a chronic inflammatory lung disease that can cause obstruction of airflow in the lungs. Symptoms include breathing difficulties, coughing, mucus production and asthma(Fig 1). This disease is usually caused by long-term exposure to irritating gases or insoluble particles(Ministry of Health Medical Administration, 2012). With the aggravation of air pollution and the increase of population aging, the incidence of COPD in China has been increasing year by year. In the past decade, approximately 3 million people have died from COPD each year(World Health Organization, 2023). It is predicted that COPD may become the third leading cause of death worldwide by 2030. In high-income countries, COPD caused by smoking accounts for more than 70% of the cases. In low and middle-income countries, COPD caused by smoking accounts for 30-40% of the cases(World Health Organization, 2023). COPD is irreversible and currently is incurable.

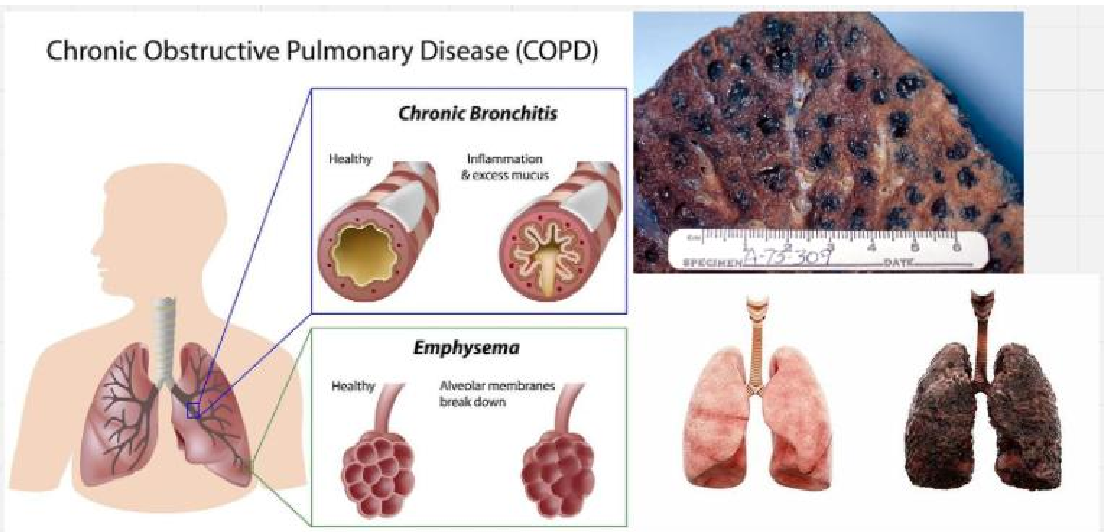

Figure 1

Treatment focuses on delaying the progression of the disease, improving lung function, enhancing the quality of life, ultimately prolong survival time and reducing the mortality rate.

Noninvasive Positive Pressure Ventilation (NIPPV) therapy is usually used in the treatment of COPD patients. NIPPV connects patients to ventilators through non-invasive methods such as using nasal masks, masks, or full-face masks, and provides positive pressure-assisted ventilation to alleviate symptoms of respiratory failure or breathing difficulties. This treatment can reduce the intubation rate of COPD patients, improve the survival rate, and can be used as a home treatment plan for COPD patients to help them maintain good respiratory function after discharge and reduce the number of hospitalizations(Chinese Thoracic Society & Chinese Medical Association Respiratory Branch Chronic Obstructive Pulmonary Disease Working Committee, 2021).

The type of ventilator used by COPD patients during NIPPV treatment is the bilevel positive airway pressure ventilator (BiPAP) among the non-invasive ventilator types. The BiPAP ventilator can alleviate breathing difficulties in COPD patients through biairway pressure-assisted breathing, and it can better help COPD patients inhale oxygen and exhale carbon dioxide, thereby improving lung gas, reducing the carbon dioxide content in the blood, and preventing acute respiratory failure in COPD patients.

This project is to study the function and structure of bileval positive airway pressure ventilator (BiPAP), design a new structure of BiPAP ventilator, and reduce the physiological limitations faced by patients with COPD during NIPPV treatment.. Integrate the problems found in the investigation into the design of the ventilator and propose an innovative solution. This solution includes the desires and demands of the end users to achieve the reduction of the limitations of portable ventilators on the physiological activities of COPD patients. My research project addressed two research issues: 1- Portable ventilators cannot provide respiratory support for COPD patients in outdoor environments because they cannot be separated from a fixed power source. 2- Portable ventilators may get damaged upon impact due to the lack of a cushioning layer, which could affect respiratory support.

This research serves as the basis of an iterative design process to propose a ventilator design can that reduces the physiological limitations and improvedcomfort. TrailBreathe is the ultimate design response that provides the best comfort and safety in ventilators.

1.0 Context Review

1.1 COPD and Treatment

In 2020, there were approximately 550 million COPD patients worldwide (about 7.4% of the total population), among which the proportion of COPD patients in Oceania was the highest (about 10.9%). In 1990, COPD caused approximately 2.4 million deaths in total(World Health Organization, 2023). By 2019, the global death toll from COPD had risen to 3.23 million(World Health Organization, 2023). In its information update on COPD on November 6, 2024, the World Health Organization (WHO) listed COPD as the fourth leading cause of death worldwide, causing 3.5 million deaths in 2021, accounting for approximately 5% of the global total. Meanwhile, the WHO has also listed COPD as the eighth leading cause of poor global health (measured by disability-adjusted life years). These data indicate the severity of COPD.

The classification system developed by the Global Initiative for Chronic Obstructive Lung Disease (GOLD) classifies COPD into four grades(Fig 2) based on the percentage predicted values of the severity of patients' symptoms and flow restriction (FEV1, forced expiratory volume in the first second of patients in pulmonary function tests).Furthermore, the GOLD system also combines symptom Assessment tools, such as the COPD Assessment Test (CAT) and the Modified Medical Research Council (mMRC). The patients were further divided into four groups: A, B, C,D (Fig 3).

GOLD Grades and Severity of Airflow Obstruction in COPD (based on post-bronchodilator FEV1) Figure 2.8

In COPD patients (FEV1/FVC < 0.7):

GOLD 1:	Mild	FEV1 ≥ 80% predicted
GOLD 2:	Moderate	50% ≤ FEV1 < 80% predicted
GOLD 3:	Severe	30% ≤ FEV1 < 50% predicted
GOLD 4:	Very Severe	FEV1 < 30% predicted

Figure 2

Description of Levels of Evidence

Table A

Evidence Category	Sources of Evidence	Definition
A	Randomized controlled trials (RCTs)	Evidence is from endpoints of well-designed RCTs that provide consistent findings in the population for which the recommendation is made without any important limitations.
	Rich body of high quality evidence without any significant limitation or bias	Requires high quality evidence from ≥ 2 clinical trials involving a substantial number of subjects, or a single high quality RCT involving substantial numbers of patient without any bias.
B	Randomized controlled trials (RCTs) with important limitations	Evidence is from RCTs that include only a limited number of patients, *post hoc* or subgroup analyses of RCTs or meta-analyses of RCTs.
	Limited body of evidence	Also pertains when few RCTs exist, or important limitations are evident (methodological flaws, small numbers, short duration, undertaken in a population that differs from the target population of the recommendation, or the results are somewhat inconsistent).
C	Non-randomized trials Observational studies	Evidence is from outcomes of uncontrolled or non-randomized trials or from observational studies.
D	Panel consensus judgment	Provision of guidance is deemed valuable but clinical literature addressing the subject is insufficient. Panel consensus is based on clinical experience or knowledge that does not meet the above stated criteria.

Figure 3

There are significant differences in drug treatment and adjuvant treatment methods among patients of different grades (Fig 4). In terms of drug treatment, Patients in the GOLD A group had milder symptoms and were usually treated with short-acting bronchodilators, including short-acting β_2 receptor agonists (SABA) such as salbutamol, or short-acting anticholinergic drugs (SAMA). Although patients in group GOLD B had a low risk of acute exacerbation, they had a heavy burden of daily symptoms. Long-acting bronchodilators were usually used, including long-acting β_2 agonists (LABA) or long-acting anticholinergic drugs (LAMA). When necessary, the two types of long-acting preparations (LABA+LAMA) could be used in combination. In the GOLD C group, even though the symptoms were relatively mild, due to the higher risk of aggravation, LAMA was the first choice for treatment. If there was still aggravation, the combined regimens of LABA+LAMA or LABA+ inhaled glucocorticoids (ICS) were used. Patients in the GOLD D group had severe symptoms and frequent exacerbations, requiring the combined medication of LABA+LAMA.

When necessary, it would be upgraded to triple therapy (LABA+LAMA+ICS). Furthermore, for some severe patients, such as those with chronic bronchitis accompanied by hypercapnia, phosphodiesterase-4 inhibitors (such as roflurast) or long-term low-dose antibiotic treatment (such as azithromycin) are required to reduce acute exacerbation.

In addition to drugs, COPD patients widely rely on inhalation devices to achieve effective drug delivery. Commonly used devices include Dry Powder Inhaler (DPI), Metered-Dose Inhaler (MDI) combined with spacers, and Nebulizer inhalation devices. The latter is more suitable for elderly, weak or patients in the acute exacerbation stage. For patients with moderate to severe hypoxemia, Long-term home Oxygen Therapy (LTOT) and portable oxygen therapy devices have been proven to improve survival rate and exercise endurance. For some critically ill patients, especially those with extremely impaired lung function, hypercapnia or nocturnal hypopnea, the use of nocturnal or long-term Non-Invasive Ventilation (NIV) equipment can be considered. In addition, pulmonary rehabilitation training equipment (such as respiratory trainers and expiratory resistance trainers) can be used to enhance the function of respiratory muscles and improve symptoms.

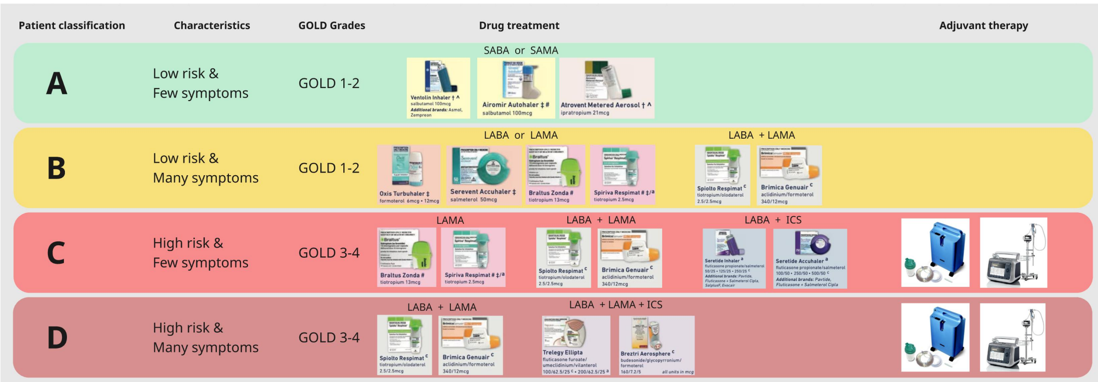

Figure 4

Non-Invasive Ventilation (NIV), as an assisted ventilation method, is mainly applicable to patients with moderate to severe COPD (GOLD grades 3-4) complicated with type II respiratory failure (hypoxemia and hypercapnia caused by pulmonary gas exchange dysfunction). COPD is one of the main causes of type II respiratory failure. If the patient has respiratory acidosis, NIV can effectively improve gas exchange, relieve respiratory muscle fatigue, reduce the rate of tracheal intubation and in-hospital mortality, and is one of the preferred respiratory support methods for AECOPD (acute exacerbation of COPD). However, for those with GOLD grades 1-2, mild limited lung function and no obvious ventilation disorders, NIV is not required.

This project is to study the function and structure of bilhorizontal positive airway pressure (BiPAP) ventilators and design a new type of portable BiPAP ventilator structure. By carrying and using the new portable BiPAP ventilator, COPD patients with GOLD 3 and GOLD 4 can receive NIPPV treatment while on the move, getting rid of the physiological activity limitations of traditional BiPAP ventilators for COPD patients during conventional NIPPV treatment.

1.2 Ventilator Woking Principle

Ventilators, as an effective means that can artificially replace the function of spontaneous ventilation, they have been widely used in the support and treatment of respiratory failure, anesthesia respiratory management during major surgeries (anesthesiology, as a component of anesthesia machines), critical care rescue (critical care medicine, emergency medicine), and home care. It occupies a very important position in the current medical field(Meng & Dan, 2025).

Ventilators can be classified into invasive ventilators(or Mechanical ventilator) and non-invasive ventilators according to the ventilation method. In the use of invasive ventilators, doctors need to directly insert the breathing hose into the patient's trachea and perform mechanical ventilation. This is usually done in medical Settings such as icus to provide ventilator support for patients with severe respiratory failure. Invasive ventilators mainly include controlled ventilation mode and assisted ventilation mode. Controlled ventilation mode refers to the complete control of the patient's breathing by the ventilator, including CMV(continuous mandatory ventilation), PCV (pressure controlled ventilation), and VCV (Volume controlled ventilation). The assisted ventilation mode allows patients to breathe independently but the ventilator will provide additional respiratory support, including SIMV (Synchronous Intermittent mandatory ventilation) and PSV (pressure support ventilation).

Non-invasive ventilators are connected to patients through non-invasive means such as nasal masks, masks or full-face masks. They usually provide respiratory support for patients with mild to moderate respiratory failure in both home and hospital Settings. Non-invasive ventilators can be classified into single-level ventilators (CPAP) and Bilevel ventilators (BiPAP) based on their functions. Single-level ventilators (CPAP) can continuously provide a constant airway pressure, helping users maintain airway normalcy and are suitable for patients with sleep apnea syndrome. The bilevel ventilator (BiPAP) can provide two different airway pressures. It offers a higher pressure when the user inhales and a lower pressure when exhaling, which helps the user better keep the airway open and reduce exhalation resistance. It is suitable for various breathing problems, including sleep apnea and chronic respiratory failure.

1.3 Product Precedent

Design precedents have greatly promoted the progress of designs aimed at reducing the physiological limitations of ventilators for patients with COPD. There are already many portable BIPAP ventilators available on the current market that can be carried around. The beneficiary group of such devices is COPD patients who need mobile treatment. They are designed in a way that combines lightweight, miniaturization and intelligent, and are suitable for travel, daily commuting and outdoor activities.

DreamStation Auto BiPAP

The DreamStation Auto BiPAP (Fig 5) primarily targets COPD patients requiring advanced ventilatory support with remote monitoring capabilities. This medical device establishes Bluetooth connectivity with the proprietary DreamMapper mobile application, enabling wireless transmission of therapeutic data to clinicians via Wi-Fi for remote parameter optimization by doctors. Key design specifications include its portability, with the main unit (excluding humidifier) weighing 1.33 kg and measuring 19 cm × 12.7 cm × 7.9 cm, ranking among the most compact BiPAP systems currently available. It features global voltage compatibility through dual voltage support (100-240 V AC and 12 V DC), eliminating the need for external converters during international travel. The incorporated ultra-quiet motor technology maintains operational noise below 30 dB (equivalent to library ambient levels), minimizing sleep disruption. Additionally, respiratory circuit and power interfaces feature foolproof latching connectors to ensure secure attachment and rapid component replacement. This integrated engineering approach addresses critical needs in mobile respiratory care, particularly benefiting patients with ambulatory treatment requirements.

Figure 5

Yuwell 925AUTO

The Yuwell 925AUTO ventilator (Fig 6) primarily serves patients with OSA and patients with stable COPD, with its clinical utility stemming from dual-mode ventilation support (CPAP/BiPAP auto-switching) that adapts to dynamic therapeutic requirements across these conditions. Regarding the Human-Machine Interface and Operational Features, the Status Indicator System utilizes a dual-color operational indicator providing immediate system feedback where Green illumination confirms standard functionality and Red illumination signifies device fault detection. In terms of Acoustic Performance, operational noise emission remains below 32 dB(A), minimizing auditory impact during sleep therapy. Key Technical Innovations include Universal Interface Compatibility through incorporation of industry-standard 22mm respiratory circuit ports, enabling cross-brand compatibility with third-party masks and tubing (e.g., ResMed interfaces). Its Localized Data Management Architecture implements WeChat Mini Program integration rather than proprietary mobile applications, facilitating cloud-based treatment report transmission for remote clinical analysis. The Advanced Humidity Mitigation System employs Multi-stage sealing featuring Circumferential silicone gaskets at housing junctions and Tapered shaft seals with desiccant infusion, complemented by an Integrated drying mechanism achieving active moisture expulsion through forced-air circulation and Hydrophobic coatings on internal components (contact angle >110°).

Figure 6

AirCurve 10 VAuto Plus C

The ResMed AirCurve 10 VAuto Plus C (Fig 7) is a portable intelligent ventilator system designed for patients requiring remote therapeutic management, particularly those diagnosed with obstructive sleep apnea and mild-to-moderate COPD (GOLD stage 2 classification). With a base weight of 1.2 kg (excluding humidifier reservoir), the system incorporates a recessed handle and non-slip base, optimizing both transportability and surface stability. To prevent motor overheating during operation, a dual-intake ventilation structure at the base effectively dissipates heat, demonstrating a 3-5°C temperature differential versus competitor units in controlled testing. The unified water tank design achieves seamless integration between humidification module and main unit, significantly mitigating leakage risks. The device exhibits robust environmental adaptation capabilities, including native compatibility with international voltage standards (100-240V AC/12V DC) without external converters and an integrated battery providing approximately 4 hours of continuous operation. Its FAA-compliant design authorizes in-flight utilization during air travel. This device can transfer the treatment data to the doctor through the mobile phone APP, facilitating the doctor to make adjustments based on the patient's treatment data.

Figure 7

ResMed AirMini

The ResMed AirMini (Fig 8) is the first-generation ultra-compact CPAP device designed for business trips and travel, which was officially launched by ResMed in May 2017. The integrated HumidX humidification technology inside this ventilator is a humidification technology that does not require water or electricity: through heat and moisture exchange (HME) technology, it uses the moisture exhaled by the patient to increase the humidity of the inhaled air, thereby achieving the purpose of humidification. AirMini weighs only 300 grams and is one of the most compact CPAP devices on the market at present. Its casing is made of high-strength polycarbonate (PC) material, which has excellent drop resistance and water resistance. Its filtration system adopts replaceable double-layer filters, which have a filtration efficiency as high as 99% and comply with ISO air cleanliness standards. AirMini comes with a dedicated mobile APP. By connecting the APP to the ventilator via Bluetooth, users can view treatment data in real time (such as AHI index, usage duration, air leakage rate, etc.) and generate PDF reports for doctors to analyze.

Figure 8

After analyzing product precedents, I found that their devices all feature lightweight designs, which are mainly reflected in the weight and structure of the devices. The devices showcased in the product precedents all weigh no more than 1.4kg, and their main units are designed in an integrated manner. I can maintain the characteristics of lightweight design in my own design. Their devices all incorporate noise reduction designs, and I need to take this into account in my design. The dual-color working indicator light and waterproof sealing structure of the Yuwell 925AUTO are excellent designs that enhance the user experience, and I will refer to these aspects in my subsequent designs.

In terms of power adaptability, they all support a wide voltage input of 100–240V AC and 12V DC power supply. This is done to meet international standards, which is an important design criterion. Since the operating environment of my design project is outdoors, I plan to design a removable battery structure to meet the power demands of various scenarios. To enhance the durability of the product, I will conduct in-depth research on the waterproof sealing structure of the Yuwell 925AUTO. In terms of intelligence, benchmarking against the devices of product precedents, I will consider designing a dedicated app to enable doctors to remotely control patients' devices and manage data. Regarding compatibility expansion, I need to ensure that my design project can be compatible with various third-party breathing tube.

The HumidX humidification system of Resmed AirMini is a waterless humidification technology, and its working principle is achieved by using a heat and moisture exchanger (HME). It is specifically divided into two parts: water vapor collection and water vapor release. The exhaled gas of the patient contains warm water vapor. When the airflow passes through the honeycomb-shaped polymer material inside the HumidX humidification box, the material will adsorb the water vapor and store heat. When the patient inhales, the dry airflow passes through the HumidX humidification box. The moisture and heat stored in the material will be released into the airflow, thereby increasing the humidity and temperature of the airflow and reducing the dryness sensation in the patient's nasal cavity. The integration of the HumidX system not only reduces the volume of the machine but also significantly reduces the demand for distilled water by COPD patients when using ventilators. I will pay attention to this design in the subsequent project design.

2.0 Initial Design Criteria

These initial design criteria are informed by relevant research findings to date and will help determine the scope and themes of this research project.

Product Function

Mobility - should allow end users to move more freely in indoor and outdoor environments without restricting their natural movements for a more comfortable use experience.

Durability - should allow end users to use the machine in indoor or outdoor environments without affecting the normal operation of the machine.

Lightweight - should allow end users to easily carry the machine for travel, business trips, outdoor activities, etc. without exceeding their load capacity.

Modularity - should allow end users to choose different components to use to meet their needs for different environments.

Replaceable - should provide users with a simpler and more convenient way to replace batteries and filter components to meet the needs of users to quickly replace new batteries and filter components in an emergency.

Product Experience

Recognition: The end user should be able to understand that this portable ventilator solution is designed to provide comfort through its structure and functions.

Distinction: A new and innovative portable ventilator should be provided that meets the needs of the end user without affecting their daily life.

Emotion: It should provide a sense of security to the end user when using it in outdoor environments.

Association: The end user should be able to recognize that the product is related to a portable ventilator for personal use.

3.0 Method and Design Process

3.1 Reverse Engineering and Product Testing

Reverse Engineering

The reverse engineering research method involves conducting reverse analysis and research on the target product, thereby deducing and obtaining design elements such as the processing flow, organizational structure, functional characteristics, and technical specifications of the product(Lu, 2016). Through this research approach, I gained an in-depth understanding of the product components, materials and structure of the ventilator. I took the SOMNOvent auto-S ventilator (Fig 9) in my hand as the anatomical object of this research. The reason why I chose this home ventilator is that it is a very classic traditional home ventilator that has appeared on the market. It has no complicated internal structure and components designed to meet the sense of compactness (Fig 10). It can more intuitively display the internal structure of a home ventilator and the relationships among its various components. The disassembly process involves separating the main shell of the ventilator to better display the internal components of the ventilator, and at the same time analyzing the shape of the main shell and the design ideas of the internal space.

Figure 9

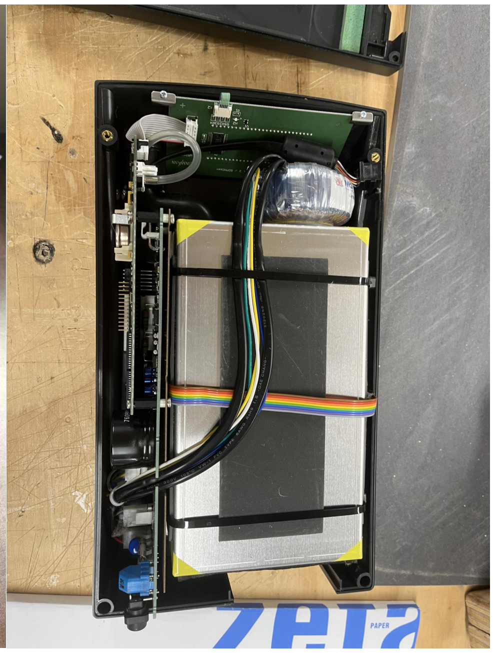

Figure 10

The housing of SOMNOvent auto-S is made of high-strength ABS material (Fig 11), which is a safety material often used for the housing of medical equipment. It has good heat resistance, weather resistance, dimensional stability and impact resistance(Chen, Fu, He, & Gong, 2014). When I analyzed this shell, I noticed that its average thickness was 4 millimeters. This thickness can enhance its protective ability, but it greatly increases the weight. Improving the overall durability of the shell by using high-strength materials and increasing the thickness of the shell is a very good design idea, and I will retain it in the subsequent design. The entire shell has only four interfaces - the breathing tube interface, the humidifier interface, the series interface and the power interface. The control panel consists of a display and four buttons, among which the four buttons respectively represent the power on, menu key, soft start mode and humidifier switch.

Figure 11

After disassembling the entire machine, I classified all the internal components into five parts: the internal air supply pipeline, the PCB board, the dual filtration system, the air pump and the air pump box. These components are all embedded in the grooves inside the machine casing. I found that the internal air supply pipe is made of rubber instead of ABS (Fig 12). The purpose of doing this should be that the internal structure of the machine is overly crowded, and the soft rubber pipe can meet the requirement of connecting the air pump and the air supply port in a crowded structure. The PCB board is designed with a double-layer structure (Fig 13). This structure not only increases the number of chips and electronic components but also protects the PCB board from damage due to compression to a certain extent. The filtration part of this machine adopts a double-layer filter (Fig 14), which is composed of a coarse filter on the outermost layer and a fine filter inside. The casing of the filter is a detachable cover made of ABS material. It has 225 holes with a diameter of 2 millimeters. It can filter out large-volume impurities in the air, such as leaves and paper scraps. The internal fine filter features an 8-millimeter-thick filter sponge and a 3-millimeter-thick HEPA filter core (Fig 15). This double-layer filter can filter out more than 99% of PM2.5 level particles and allergens in the air(Obitková, Mráz, & Pavlík, 2024). The air pump of the ventilator uses a brushless DC turbine air pump (Fig 16). This type of air pump is characterized by high efficiency, good controllability and low noise, etc. Most medical ventilators use this type of air pump. The pressure range it can provide is 4-25 cmH_2O (with an accuracy of ±0.3 cmH_2O), which is also the airflow pressure that most COPD patients can withstand(Chen, Dong, & Cao, 2024). Since this air pump is fixed by support rods, it usually shakes when it is working. The sponge layer inside the air pump box can reduce vibration, lower noise and has a small filtering capacity. SOMNOvent auto-S adopts an electric heating type humidifier (Fig 17). After the heating rod inside is powered on, it will heat the pure water in the humidifier to the preset temperature. The filtered air delivered from the air pump combines with the warm water vapor in the humidifier and is delivered to the user's lungs through the breathing hose.

Figure 12

Figure 13

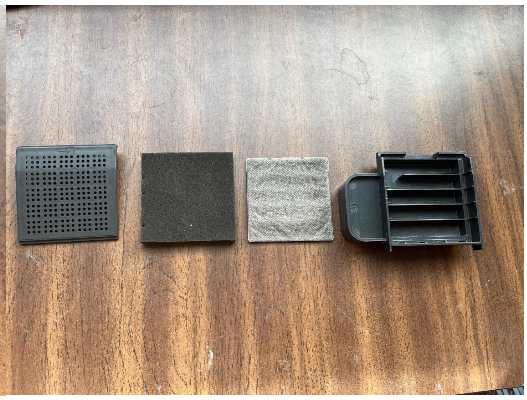

Figure 14

Figure 15

Figure 16

Figure 17

By dissecting the machine, I learned about the internal structure of the ventilator and the function of each component. Some of these designs can be extended to my subsequent designs. For example, the shell is made of high-strength materials and the thickness of the shell is increased to enhance the strength of the shell. Double-layer filtration is adopted and HEPA high-efficiency filters are used to achieve the purpose that the portable ventilator can efficiently filter the air outdoors. The adoption of brushless DC turbine air pumps capable of providing a pressure range of 4-25 cmH_2O can meet the respiratory needs of most COPD patients.

Product Testing

To further study portable ventilators, I decided to simulate this user experience by testing the ventilator models I used in my self-log research. I simulated the SOMNOvent auto-S ventilator as a portable ventilator that can be applied in outdoor environments. I put it in my backpack and carried it to the outdoor environment for testing(Fig 18, 19). Through application tests in different environments, I can intuitively understand the various demands that users will have in different environments.

Figure 18

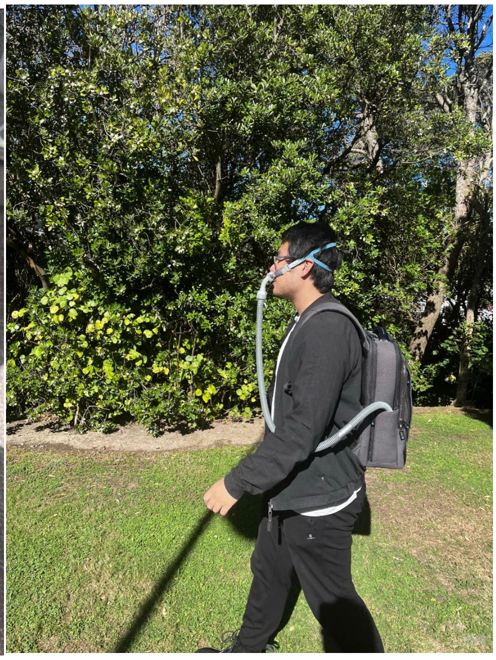

Figure 19

When going out, due to the large size and weight of the ventilator, I have to carry it in a backpack. During the process of using the test, I often couldn't see the low obstacles on the road because of the breathing mask, so my feet often kicked things. Another drawback of the breathing mask is that when the outdoor temperature is extremely high, during the wearing process, sweating often leads to a poor fit between the mask and the facial skin, which may cause air leakage and thus affect the treatment effect. When it's windy on the street, the breathing hose is often blown and drifts. This is because the breathing hose is not fixed. This situation is even more serious by the seaside, to the extent that I have to keep holding the breathing hose with one hand all the time. Whenever I need to set the working mode or check the remaining battery power, I have to take the ventilator out of my backpack for operation. After completing the Settings, I put it back in my backpack. This is a very cumbersome process. I need to carry a 500ml bottle of distilled water with me to meet my need to add water to the humidifier during use. Since this ventilator doesn't have a built-in battery, I need to carry an additional power bank to support the operation of the ventilator, which greatly increases my burden. After I turned on the humidifier, the ventilator's demand for power doubled. As a result, the battery that could have lasted for 4 hours could only last for 1.5 to 2 hours after the humidifier was turned on.

Through simulation tests, I learned that the breathing mask is a component that greatly affects the field of vision, especially in outdoor environments. Therefore, in the subsequent design process, I need to take into account the matching degree between the breathing mask and the environment. The battery life is relatively short. When traveling, it cannot guarantee sufficient power, and frequent charging is required when used for a long time. Because the humidifier has very high requirements for water quality, I need to carry distilled water with me, which indirectly increases my burden. I also need to consider the fixation method of the breathing hose during the design. The convenient and fast human-computer interaction system is also the part that I need to focus on thinking about.

3.2 Research Through Design

I employed an iterative design process in my design research. This approach was advantageous in that it allowed me to draw inspiration from insights and established concepts, investigate and test prototypes, and refine them through comprehensive research and evaluation. This was accomplished by following a cyclical four-step process that entails the following: comprehending the research's purpose and objectives, analyzing end-user insights, visualizing insights through sketching and prototyping, and comparing them to the initial goals and design criteria of the project research.

Design Research Methods

Sketching: This was an important form of research and iterative development used to evaluate ideas generated from research insights to help shape the final design and each major component. This design process was carried out throughout the research project.

Modeling and Prototyping: Physical prototypes and Solidworks software helped turn Sketchup into three-dimensional shapes, capturing the ideas that were produced during the original concept creation phase. The models and prototypes under development advanced in complexity and resolution throughout the design study, culminating in a model that replicates how the finished design would appear in a finished product. Improved testing and assessment of function, proportion, and aesthetics were also made possible by 3D modeling and prototyping throughout the design process.

3.2.1 Concept Generation

The ventilator is a rather complex product composed of various electronic components and physical parts. Since I have no relevant knowledge in the field of electronic engineering, this research project will not develop the electronic components involved in the ventilator. Only the conceptual design of the overall appearance, internal structure and functions of the ventilator is proposed.

The initial concept was directly inspired by the initial design standards. First, I focused on creating concepts around the appearance and function of the ventilator, and then also designed the internal structure of the device and various components (Fig 20). In order to better understand some of the generated concepts, especially when transitioning from two-dimensional to three-dimensional, I created rough sketches and prototypes based on these concepts.

Figure 20

Concept 1 : Backpack portable ventilator

This concept focuses on making ventilators more suitable for users to carry around (Fig 21,22). In this concept, I retained all the components of the traditional home ventilator and added a built-in power supply to it to meet the ventilator's power requirements. Since the appearance of this concept is close to that of a backpack, I took the existing backpack as the prototype. I put all the ventilator components in my backpack and placed a bottle of water in it to simulate the design of the built-in humidifier. There is an independent control panel design at the shoulder, which can be used to monitor various data of the ventilator. Patients can also set the mode of the ventilator through it. The breathing hose can also be fixed in the shoulder strap.

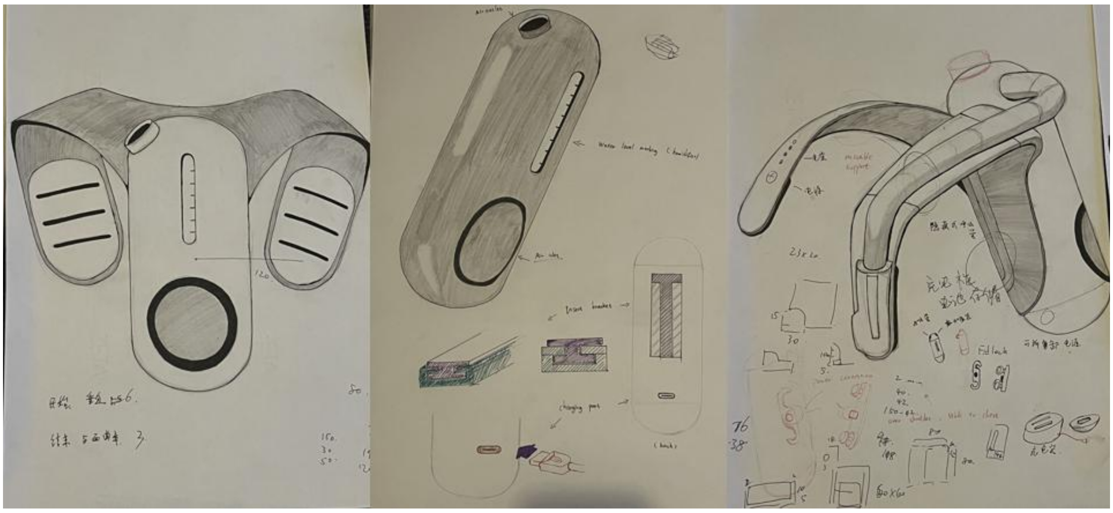

Figure 21

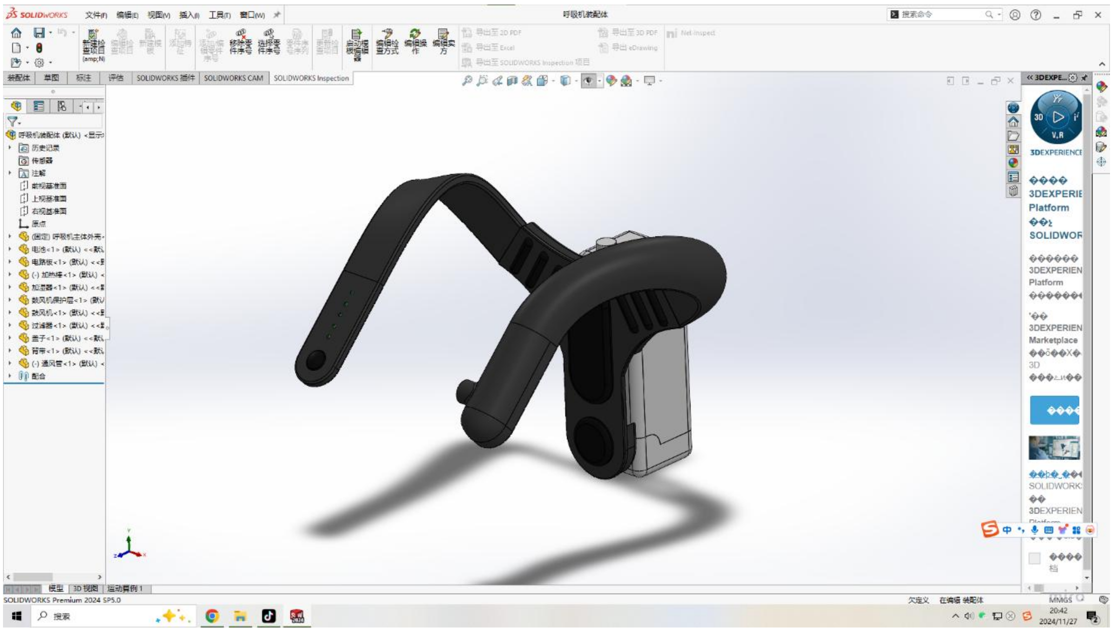

Figure 22

When I was making a prototype and conducting tests (Fig 23), I discovered that the most fatal design of this concept is that it actually makes COPD patients carry a large box, and this large box will prevent them from leaning normally when sitting down. Since the main unit is at the back, when COPD patients are using it, they need to remove the shoulder strap and the machine to replace the battery and add distilled water to the humidifier. This process is very troublesome.

Figure 23

This concept design does not match my initial idea of making it easy for COPD patients to carry without affecting their normal physiological life.

When I reanalyzed the product precedents, I found that nowadays portable ventilators are hardly equipped with humidifiers. This is because humidifiers usually require more space and weight. For portable devices, reducing the humidifier can significantly lower the volume and weight, making them more suitable for daily carrying in travel cases. Moreover, the humidifier requires an additional power supply. Removing the humidifier can extend the battery life of the device. Therefore, I have decided to choose the existing humidification system on the market to replace the traditional humidifier in the subsequent design.

I have decided to reduce the size and weight of the machine in the following design to make it easier to carry, which will be more in line with the main body of portable devices.

Concept 2 : Modular portable ventilator

This concept is designed to meet the end users' demands for the modularization and replace-ability of ventilators, in order to address the adaptability of ventilators to different environments (Fig 24). In this concept, I hope the battery can be easily replaced. Because in the complex outdoor environment, fewer battery replacement steps can reduce the occurrence of potential risks. The feature of this concept is a modular small machine. The reason why I designed it this way is that I hope it can be easily put into the pocket of clothes.

In this concept, I hope the storage device for breathing hoses can also be carried around. So I tested two different breathing hoses （Fig 25）. After the test, I found that a 70-cm-long breathing hose (including both thick and thin ones) is completely sufficient for daily use. Then I tried different winding storage methods and measured the size (Fig 26).

Figure 24

Figure 25

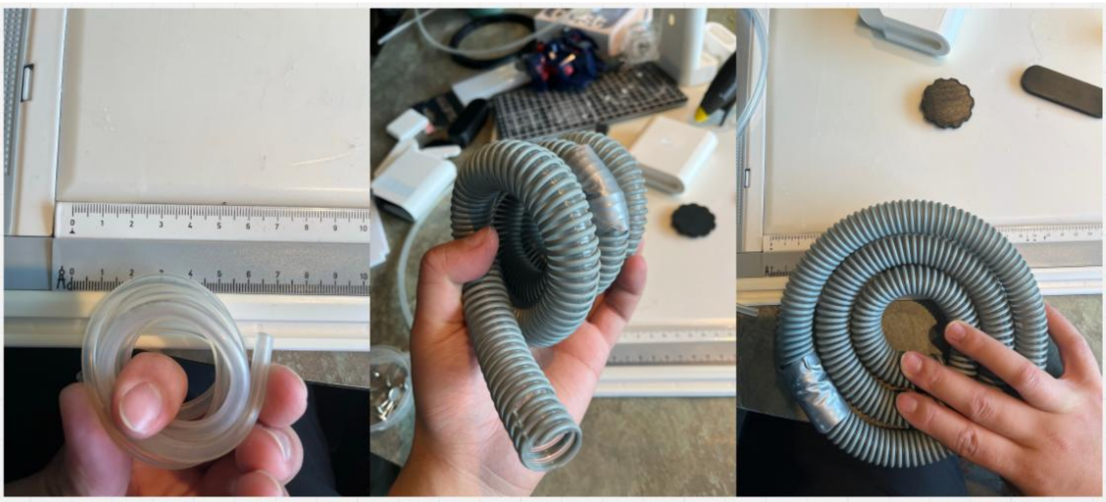

Figure 26

After I designed the storage components (Fig 27) for the two types of breathing hoses respectively, I found that they both had some drawbacks. The storage space for thin and soft tubes is very small, they are difficult to clean and have cleaning dead corners. And frequently bending the hose will also increase the risk of breakage. However, the storage component of the thick hose also has cleaning dead corners. Moreover, due to its large volume, it cannot be put in a pocket and still needs to be paired with a bag when in use.

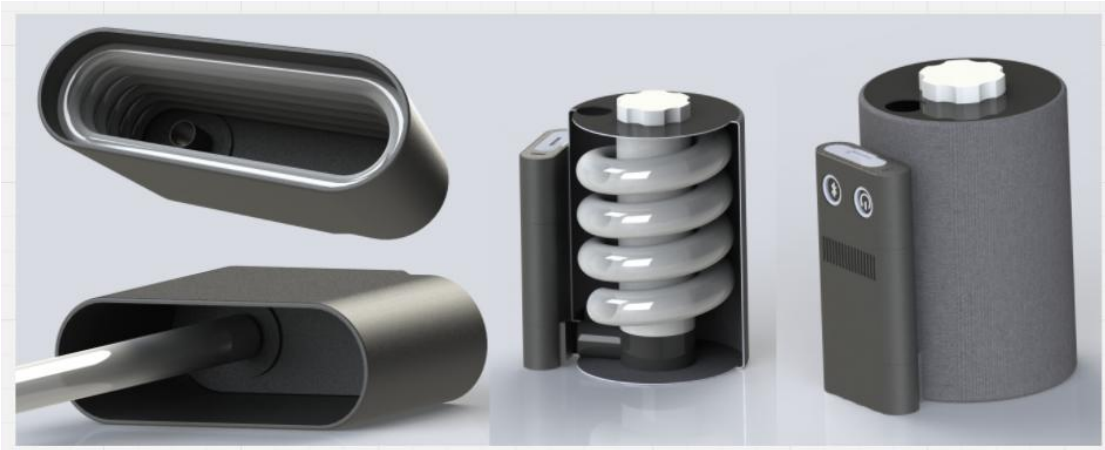

Figure 27

The limitation of this concept lies in the fact that each component of the ventilator is independent, resulting in poor integrity of the ventilator. Moreover, the exposed components become more fragile due to the lack of casing protection, thereby increasing the risk of damage and maintenance costs. Too many components will instead increase the complexity during use and make it more difficult to operate in outdoor environments. Meanwhile, when I was designing at the beginning, I found that the thin breathing hose could only be used for oxygen inhalation rather than for the treatment of COPD, which made me give up choosing the thin breathing hose.

Inspired by this concept drawing, I decided to abandon the concept of portable breathing hose storage in subsequent designs. Meanwhile, in order to reduce the risk of damage to the machine, I decided to design all the components except the battery and the filter in the same main body and add a protective layer to this main body. And when I was designing this concept, I found that the thin breathing hose could only be used for oxygen inhalation rather than for the treatment of COPD, which made me give up choosing the thin breathing hose. The main idea of this is to enhance the protection of portable ventilators and increase their durability in complex outdoor environments.

Concept 3 : Smaller portable ventilators

Here, I was inspired by the design of the "mobile Bluetooth speaker", this concept that focuses on making it easier for COPD patients to carry ventilators without affecting their daily lives by reducing the functions of some ventilators and compressing their components (Fig 28). This concept employs the integrated HumidX humidification technology, which not only keeps patients inhaling moist air but also frees up the overall volume and weight that would have been increased by carrying a humidifier.

Figure 28

The core of this design is to further compress the volume without affecting the basic functions of the portable ventilator. To meet this design core, I only retained the air pump, filtration system, PCB board and battery inside the portable ventilator. This concept has better structural stability compared to the previous two and will not decompose due to bumps and knocks. And in my conception, its shells should be made of high-strength ABS+PC material, and the surface should be covered with a soft rubber skin. This soft skin can provide good anti-slip and shock-absorbing effects.

3.2.2 Concept Evaluation

After analyzing and comparing the ideas I generated during the concept creation phase, my initial design criteria, and the insights gained from my research, I was able to identify four design directions to guide my updated design criteria.

Human-computer interaction system: In order to satisfy the needs of users to focus on the activity itself rather than operating the equipment in a complex outdoor environment, while ensuring the safety and continuity of respiratory supply, an intelligent human-computer interaction system that can be operated with one hand is necessary. From my product precedent research, I found that a simple operation panel plus a mobile phone APP connected via Bluetooth can meet this demand.

Energy supply: In order to meet the needs of this research project to provide respiratory support for COPD patients for a long time in outdoor environments, designing a replaceable battery and a built-in charging system for the ventilator is an effective strategy. This design solution can improve the portability of the ventilator as a medical device.

Filter system: In order to effectively meet the needs of users to obtain close to medical-grade respiratory protection in complex outdoor environments, it is necessary to design an efficient filter system. This filter system needs to be designed to be replaceable to ensure that the ventilator can continue to provide clean air.

Equipment sealing property： To ensure the durability and normal operation of the equipment in outdoor environments, it is very necessary to design a waterproof sealing structure. The target of this waterproof sealing structure is the moisture vapor from the outside of the equipment. The ventilation openings of the equipment also need to be designed for waterproof sealing.

3.2.3 Final Design Criteria

Product function

Mobility: COPD patients should be allowed to move more freely in indoor and outdoor environments when using the ventilator without restricting their natural movements for a more comfortable use experience. They should be able to easily carry the ventilator for travel, business trips, outdoor sports, etc., without exceeding their weight. Use replaceable battery modules to achieve long battery life. The overall size and appearance of the ventilator should not be allowed to affect the patient's daily life. Avoid using stainless steel or alloy materials and structures, and use high-strength engineering plastics (such as ABS, etc.), which can reduce weight by more than 40%. Inefficient use of the internal space of the ventilator is not allowed, and all internal space must be used for core functions.

Durability: COPD patients should be allowed to experience bumps and scratches during use without affecting the normal operation of the machine. All-round protection made of high-strength engineering plastics (such as ABS, etc.) that are allowed to be used in medical equipment can prevent bumps and scratches. When the equipment operates in an outdoor environment, it should have good waterproof sealing performance. External moisture and water vapor should not seep into the equipment due to design reasons, thus not affecting the normal operation of the equipment.

Replaceable: COPD patients should be provided with a simpler and more convenient way to replace batteries and filter components to meet the needs of users to replace new batteries and filter components in an emergency. The process of replacing batteries and filter components must allow patients to operate completely barehanded to avoid being unable to replace them when using them outdoors due to lack of tools.

3.2.4 Component Design Development

This part of the design research focuses on the design and development of six key components of the ventilator: Human-Machine Interaction system, Energy supply, Anti-slip layer, Filter system, Breathing hose interface and Equipment sealing property.

Human-computer interaction system: When developing the human-computer interaction system, I used the results obtained in the product precedent investigation - designing a simple operation interface with only two buttons plus a mobile phone APP connected via Bluetooth. In this part, I focused on developing the feedback mechanism of the buttons and the mobile phone APP function. After investigating the buttons of common household devices (Fig 29), I concluded that designing a raised relief of the function logo on the surface of a push-button with vibration feedback allows users to know the function and working status of the button even if they don’t look at the device (Fig 30) .

Figure 29

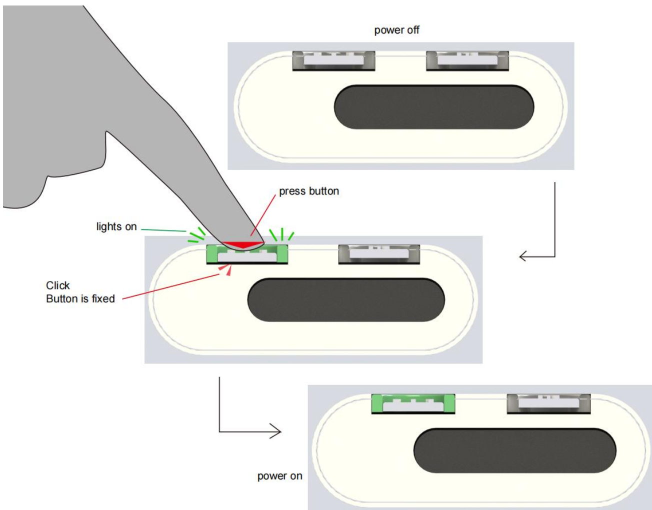

Figure 30

When designing the functions of the mobile app, I took into account possible user needs, such as device parameter display, parameter settings, user data, and data sharing (Fig 31).

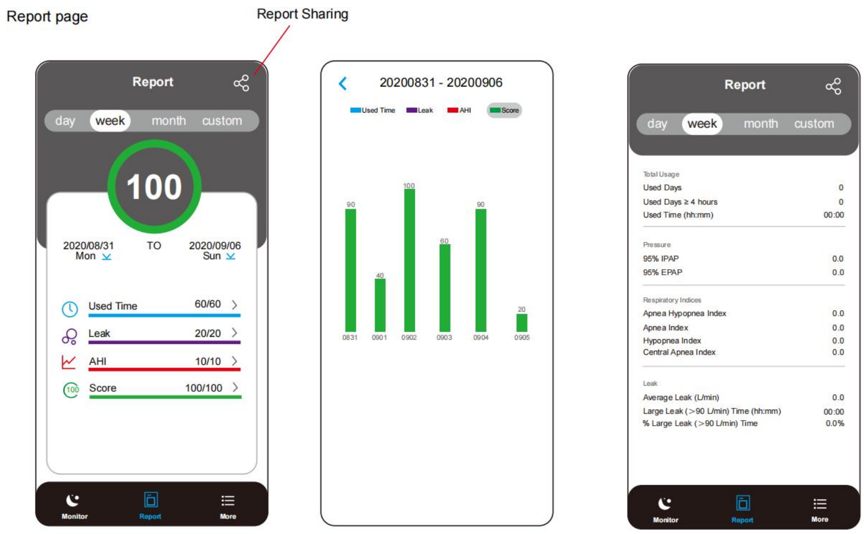

Figure 31

Energy supply: After investigating common replaceable batteries (Fig 32), I found that compared with traditional battery technology, lithium-ion batteries charge faster and last longer, and the higher power density can achieve longer battery life while being lighter. Lithium batteries can meet the requirements of replacing batteries in outdoor environments while maintaining a light weight. USB-C is the best conclusion I came to after investigating the charging system of electronic devices. Most devices today are equipped with USB-C interfaces, which means that COPD patients no longer need multiple cables and chargers, making it easier for them to use and manage devices. In the design, I decided to design the battery as a replaceable structure and enable power replenishment via USB-C.

Figure 32

Anti-slip layer: In order to improve the stability of the ventilator, I focused on developing an anti-skid layer, which is usually used on the bottom and shell of various devices to provide the device with just the right stability. I referred to the anti-skid parts of common home electronic devices on the market (Fig 33), and I found that the design of the anti-skid part depends on the functional positioning of the electronic device: when a device hardly moves, its anti-skid part is small; and when a device appears outdoors, its anti-skid pad will also be accompanied by special textures. I simulated and tested the adaptability of different anti-skid pad forms to the environment to determine which one works best (Fig 34). Since I changed the appearance design of the project before, I decided to combine the anti-slip layer with the shell (Fig 35). Since the anti-slip layer is mostly made of elastic rubber and has a certain buffering capacity, if the shell of the portable ventilator is designed to be made of elastic rubber with anti-slip patterns, the protective ability of the shell will be greatly enhanced.

Figure 33

Figure 34

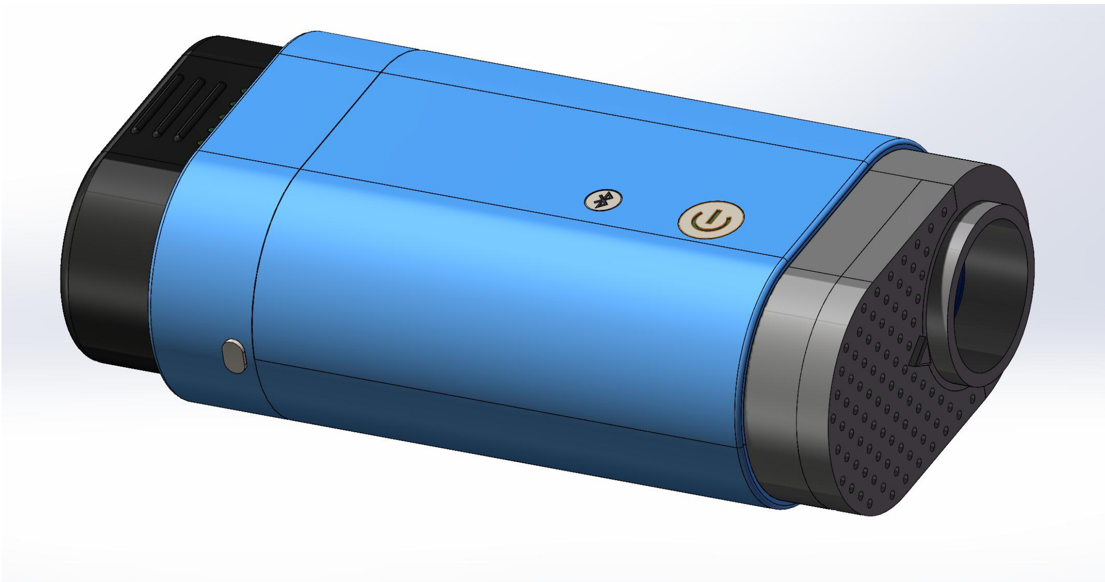

Figure 35

Breathing hose interface: I had been planning to incorporate the HumidX system into my design, but after investigating, I discovered that the HumidX system has certain limitations. It only maintains airflow humidity within a 20 cm range from the face, and it was typically being connected to breathing masks, such as the BMC P2H nasal mask (Fig 36). Therefore, to achieve humidified airflow while eliminating the humidifier, I was redesigning the ventilator's tubing interface (Fig 37). This redesign was enabling it to be compatible with most respiratory tubing available on the market, as well as with breathing masks equipped with the HumidX system.

Figure 36

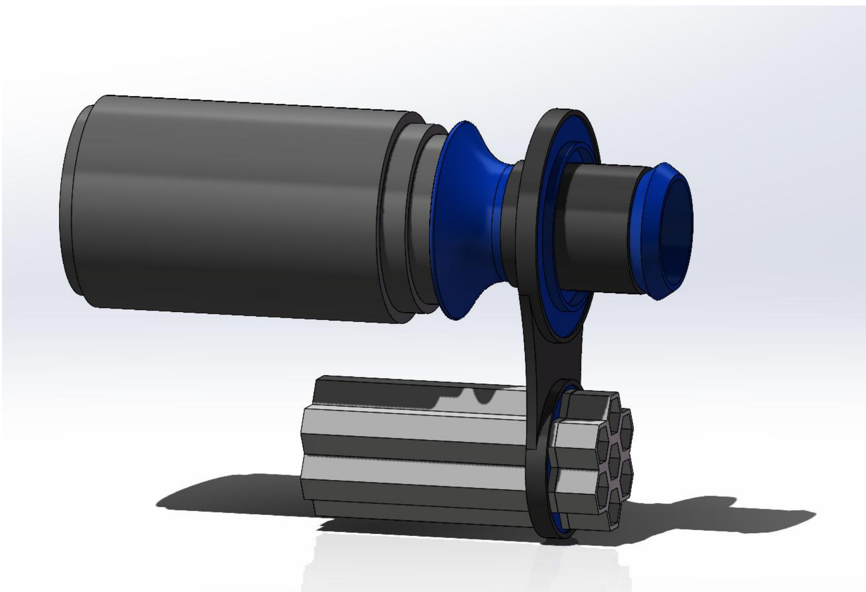

Figure 37

Equipment sealing property： The sealing performance section includes the sealing design of the breathing tube interface, the sealing design of the power interface and the battery compartment, as well as the sealing design of the main body of the ventilator. At the interface of the breathing hose, I designed an elastic rubber gasket (Fig 38). This can not only effectively prevent air leakage, but also prevent the air outlet from colliding with the breathing hose and getting damaged.

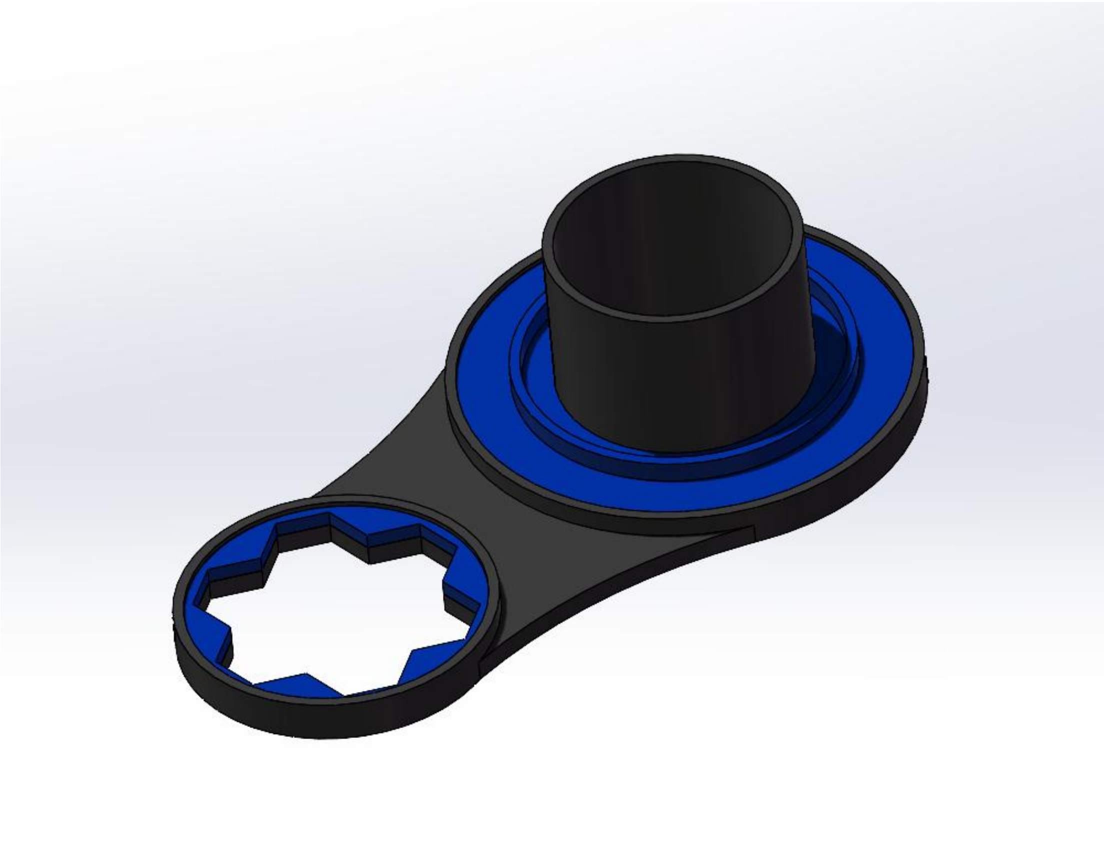

Figure 38

Filter system: The filters of ventilators are basically composed of a filter housing and a filter element (Fig 39). The filter housing is usually made of ABS plastic, while the filter element is typically compressed from medical-grade cotton. Nowadays, portable ventilators on the market are designed with replaceable cards to improve the efficiency of filter element replacement. Whenever the filter element needs to be replaced, the user can easily pull out the old card and insert the new one to complete the task. Inspired by this design, I decided to add the structure of replaceable filter elements to my design. Considering the air quality of the outdoor environment, I decided to increase the number of filter elements, and I designed the filter elements to match the shape of the filter part of the ventilator, and also designed a positioning structure to prevent detachment(Fig 40).

Figure 39

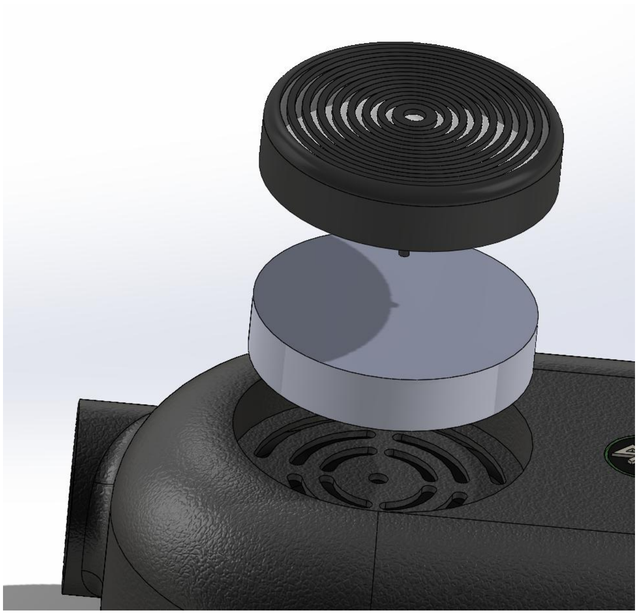

Figure 40

4.0 The Final Design

TrailBreathe

TrailBreathe (Fig 41) is a portable ventilator designed for COPD patients. It is designed and manufactured to reduce the physical weakness caused by long-term use of traditional ventilators in COPD patients. TrailBreathe aims to help COPD patients return to normal daily life through innovative design, thereby avoiding the vicious cycle of physical weakness. It allows COPD patients to put it in their pockets and backpacks and carry it to outdoor environments. The lightweight component design can reduce the overall volume while ensuring the full function of the ventilator, and will not affect the daily life of COPD patients when using it.

Figure 41

Key Components and Benefits

Anti-slip shell: The outer protective casing utilizes high-strength ABS engineering plastic (Fig 42), achieving a 30% weight reduction compared to traditional metal enclosures while maintaining exceptional structural rigidity. On the casing surface, a specialized 0.5mm-thick silicone rubber coating is applied through dual-curing process. These features collectively provide comprehensive protection for portable ventilators during field deployment in challenging environments such as EMS transport, high-humidity coastal areas, and sub-zero mountainous terrain.

Figure 42

High-efficiency filter sandwich: The high-efficiency filter (Fig 43) inter layer with multiple layers of medical-grade cotton filters superimposed can capture more than 99.97% of particulate matter ≥0.3 microns (such as PM2.5, pollen, bacteria and viruses), providing air purification capabilities close to medical grade. The appearance design of the filter sandwich reduces its volume while maintaining high-efficiency filtration performance. When the air is sucked into the ventilator, it will pass through three layers of filtration. The first layer can roughly filter out large particles of dust and dirt in the air. The second layer is the air filter element, which can filter out 98% of pollutants while ensuring smooth air circulation. The third one is the honeycomb-shaped sponge filter core. Its presence can effectively absorb most of the pungent odors in the air (such as musty smell), making the air entering the air pump purer.

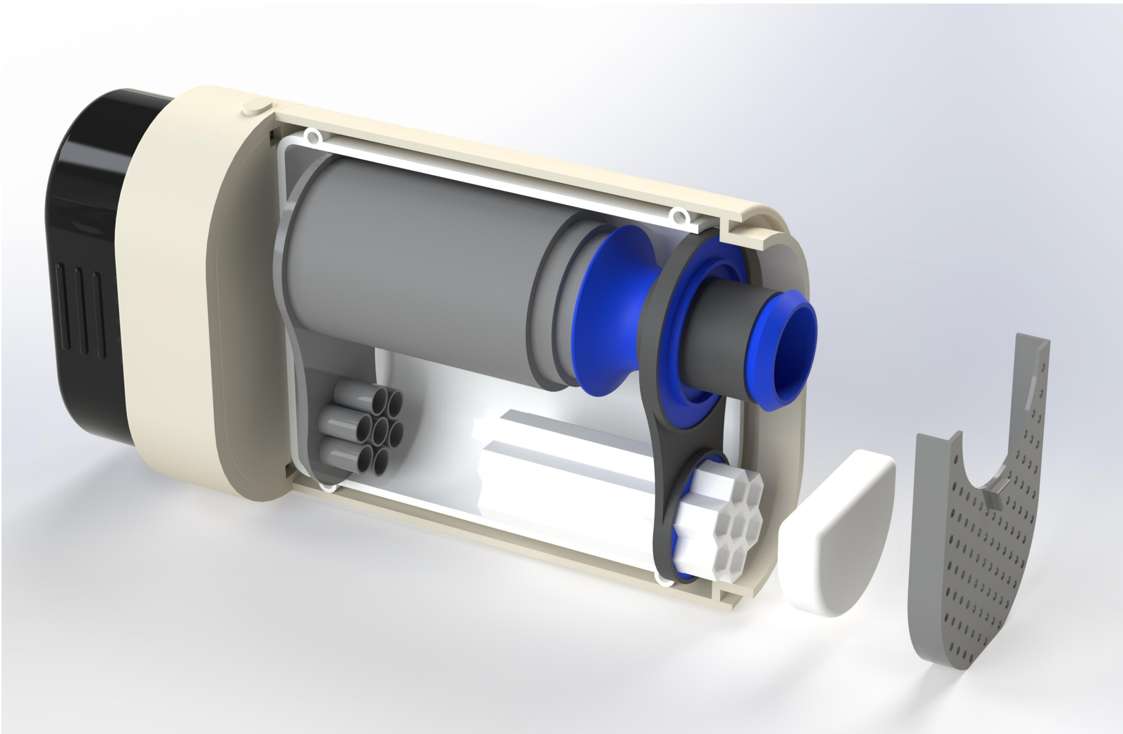

Fig 43

Battery compartment: Through the design of modular battery components (Fig 44), COPD patient can quickly replace the energy of TrailBreathe in outdoor scenes, effectively ensuring the continuous operation of the equipment. Its modular structure reduces maintenance costs, and only new batteries need to be replaced after the old batteries are aged. The innovative design of this dual energy supply system not only extends the working time of TrailBreathe, but also significantly improves its environmental adaptability. The battery employs a 4.0Ah lithium iron phosphate (LFP) cell with a total capacity of 47 Wh. This cell chemistry delivers excellent performance stability and superior safety performance with proven reliability, having been widely adopted in the new energy vehicle (NEV) sector. Compatible with universal voltage ranges (100-240V AC / 12V DC), it can continuously power the 6.3W air pump for 6 hours. Calculated at a minimal weight of 480g. Recharging is accomplished via a USB-C (Power Delivery) port, requiring only 4 hours for a full charge cycle. When inserted into the battery compartment, the cell is securely retained by integrated latching mechanisms that provide positive engagement. The compartment design features an interface-sealing structure that automatically covers the USB-C port upon full insertion, effectively preventing ingress of dust, moisture, and mechanical damage.

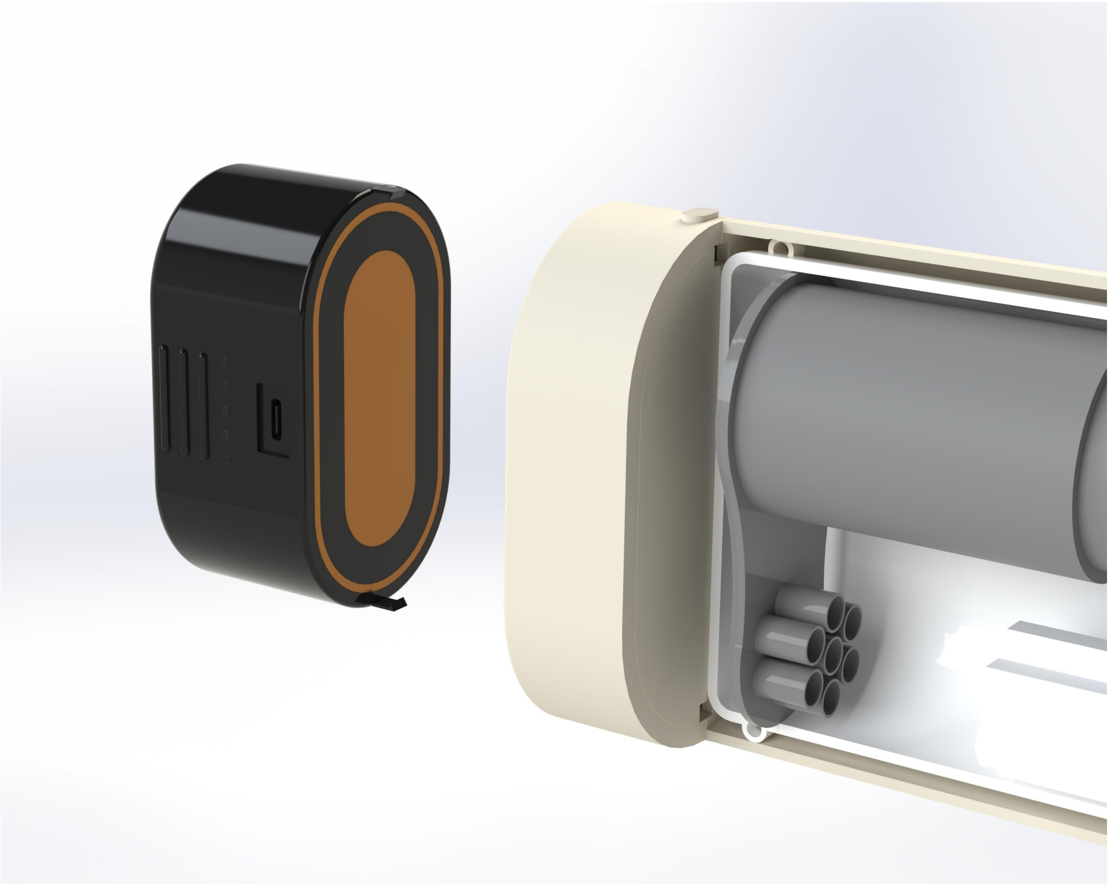

Figure 44

Buttons with prompt functions: Illuminated status indicators enable intuitive operational awareness (Fig 45). The power button emits a steady green light when the TrailBreathe is actively operating, while a red illumination signifies standby/off mode. The Bluetooth pairing button features an icon-embedded LED that activates in pulsating blue when the device has successfully established a mobile app connection. This indicator deactivates immediately upon Bluetooth disconnection. Tactilely differentiated button sizes enable COPD patients to identify control functions through haptic confirmation. This somatosensory interface maintains operational accuracy even when wearing medical gloves.

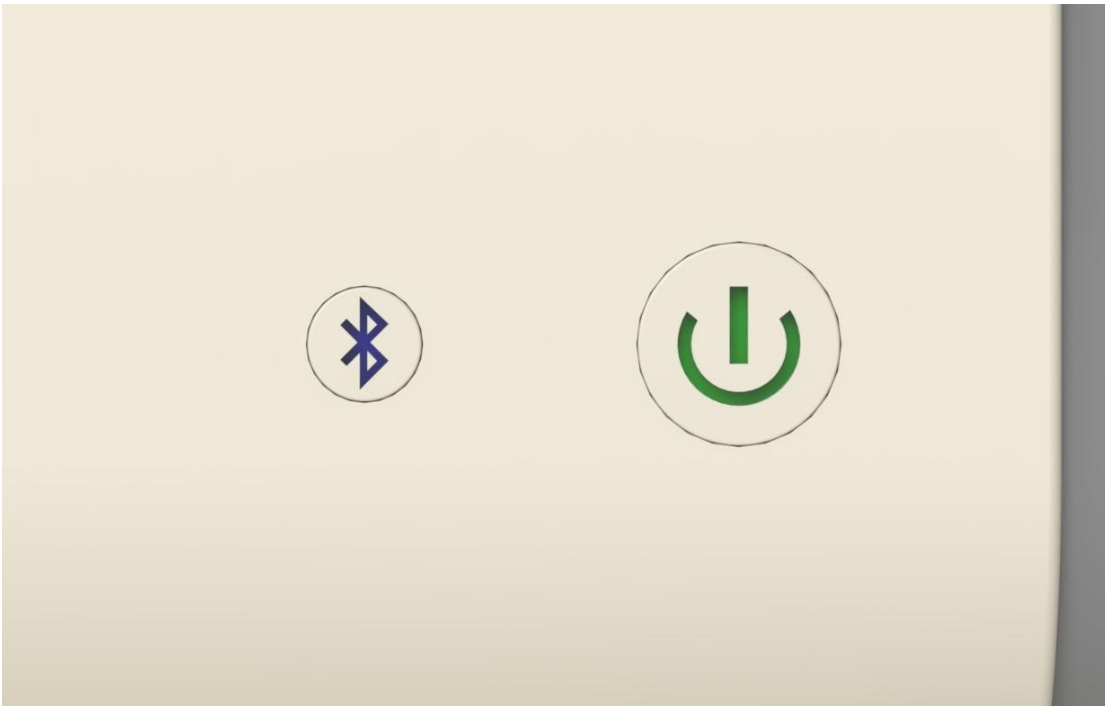

Figure 45

5.0 Conclusion

This design study explored how to use ventilator design to reduce the debilitation of COPD patients caused by long-term use of ventilators, and to meet the needs of COPD patients through innovative design solutions. TrailBreathe is a portable ventilator designed for COPD patients, aiming to help COPD patients return to normal daily life through innovative design. This ventilator is designed to respond to the increased demand for ventilators caused by the increase in the number of COPD patients since the COVID19 epidemic in 2019. At present, traditional ventilators have physiological and range limitations when using ventilators due to their product characteristics (such as inability to leave a fixed power source and large device size), which aggravates their debilitation. TrailBreathe provides the power requirements of the device to work in outdoor environments through its compliant replaceable battery assembly design. The breathing hose storage assembly allows COPD patients to quickly remove and store the breathing hose, and the magnetic suction design can better fix the breathing hose to the designated place of the COPD patient (such as clothes, backpacks, etc.). The shell made of high-strength ABS material with a special non-slip texture increases friction with the surface of the object, improves the stability of the device, and also prevents the device from collision and scratching.

My research process has provided me with a more profound comprehension of the design requirements for ventilators to alleviate the limitations of COPD patients, as well as the ways in which key product components contribute to the overall experience of COPD patients. Throughout the design development process, I acquired an understanding of the value of an iterative design process and the significance of visualizing insights through sketching based on prototypes. This endeavor has prompted me to recognize the vast amount of knowledge in the field of design that remains to be acquired, and it has also offered me direction for future learning.

TrailBreathe includes innovative design features for COPD patients. However, I find that some design inspirations can also be applied to different areas of the medical device design industry to help improve the patient experience. Standardized module component design can be applied to other medical device fields that need to meet different needs, such as surgical instruments. At the same time, standardization will promote industrial chain collaboration, reduce production costs, and support the recycling of old modules, reducing resource waste. It is a key technical path for medical devices to move towards intelligence and personalization. I hope it can inspire future medical device innovation and improve the patient experience.

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List of Figures

Fig.9 - The appearance of the SOMNOvent auto-S ventilator, photography by Yuhang Qin, 2024

Fig.10 - The internal structure of the SOMNOvent auto-S ventilator, photography by Yuhang Qin, 2024

Fig.11 - The casing of the SOMNOvent auto-S ventilator, photography by Yuhang Qin,2024

Fig.12 - The internal air delivery hose of the SOMNOvent auto-S ventilator, photography by Yuhang Qin, 2024

Fig.13 - The PCB of the SOMNOvent auto-S ventilator, photography by Yuhang Qin, 2024

Fig.14 - The filtration component of the SOMNOvent auto-S ventilator, photography by Yuhang Qin, 2024

Fig.15 - The various components that make up the filtration system, photography by Yuhang Qin, 2024

Fig.16 - The air pump inside the SOMNOvent auto-S ventilator, photography by Yuhang Qin, 2024

Fig.17 - The humidifier that comes with SOMNOvent auto-S ventilator, photography by Yuhang Qin, 2024

Fig.18 - Simulation test, carrying a ventilator for outdoor use, photography by Yuhang Qin, 2024

Fig.40 - Design scheme of filtration component through Solidworks, modeling by Yuhang Qin, 2025

Fig.41 - The final designed 3d model through Solidworks, modeling by Yuhang Qin, 2025

Fig.42 - Display of the final designed 3D model anti-slip pad through Solidworks, modeling by Yuhang Qin, 2025

Fig.43 -Display of the final designed 3D model filtration system through Solidworks,modeling by Yuhang Qin, 2025

Fig.44 - Display of the final designed 3D model battery compartment through Solidworks, modeling by Yuhang Qin, 2025

Fig.46 - Display of the final designed 3D model indication buttons through Solidworks, modeling by Yuhang Qin, 2025

Appendices

All the investigation materials are summarized in Miro board

https://miro.com/app/board/uXjVOJG4ChM=/