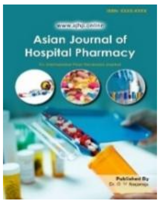
Review Article

Asian Jour Hosp Phar, Vol: 6, Issue: 1, 2026, 1-8

Asian Journal of Hospital Pharmacy

Content Available at www.ajhponline.com ISSN: 2583-0724



A REVIEW OF RECENT ADVANCES IN THE DEVICES FOR THE TREATMENT OF CHRONIC OBSTRUCTIVE PULMONARY DISEASE

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Received: 19.12.2025 Revised: 17.01.2026 Accepted: 09.02.2026

ABSTRACT

A frequent respiratory condition with a high morbidity and mortality rate is chronic obstructive pulmonary disease (COPD). Many people do not receive a diagnosis until the disease has progressed clinically, and COPD is underdiagnosed despite its prevalence. Current studies on early COPD modifications aim to identify people for early intervention, enhance diagnostic, and uncover new targets for treatment. Over the past 20 years, there has been a significant increase in the number of COPD therapies available due to this focus, new oral and inhaled drugs, and innovative procedures. The gradual lung dysfunction known as chronic obstructive pulmonary disease (COPD) is mostly brought on by smoking cigarettes and breathing in harmful particles. The persistent exposure to disastrous chemicals might lead to aberrant inflammatory reactions, permanent damages to the respiratory system, and irreversible pathological alterations. Mitochondrial and epigenetic changes are increasingly recognized as playing a role in (COPD) development, alongside genetics and aging. these alterations include mitochondrial damage, excess production of reactive oxygen species, abnormal the cell's self-cleaning process, and altered and (programmed cell death). Epigenetic modifications like DNA methylation, histone.

Keywords: *COPD, pulmonary rehabilitation, digital health, exacerbations, inhaler technique, machine learning, and patient involvement.*

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DOI: https://doi.org/10.38022/ajhp.v6i1.125

INTRODUCTION

Definition

Globally, chronic obstructive pulmonary disease (COPD) is a significant public health concern and the third highest cause of mortality [1].

The lung ailment known as chronic obstructive pulmonary disease (COPD) usually gets worse with time. The primary cause is prolonged exposure to irritants like tobacco smoke, indoor and outdoor air pollution, and hazardous dust and fumes from the workplace. These irritants cause damage and inflammation in the lungs [2].

In addition to systemic consequences like fatigue, frailty, and decreased exercise tolerance, patients with COPD often have a variety of lung symptoms, such as coughing, sputum production, and dyspnea [3].

Emphysema damage to the lung air sacs and chronic bronchitis, a long-term inflammation of the airways, are the two main conditions that make up chronic obstructive pulmonary disease (COPD), a collection of lung conditions that permanently compromise lung function [4].

The World Health organization reports that COPD is the third most common cause of death worldwide, affecting 65 million people and resulting in over 3 million deaths annually. Additionally, it is estimated that low- to middle-income countries account for about 90% of the mortality rate [5].

The lungs experience an aberrant inflammatory response when exposed to harmful particles or gases. Emphysema and chronic bronchitis, two major symptoms of COPD, are brought on by this immunological response. This process causes lung abnormalities, such as the expansion and destruction of air sacs, as well as airway blockage [6].

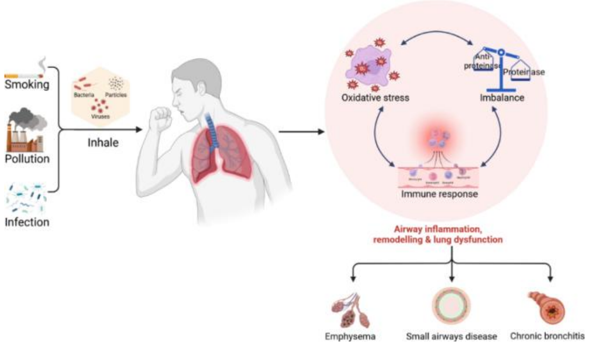

Fig 01.the pathogenesis of COPD

HISTORY

Chronic obstructive pulmonary disease (COPD) is a long-term lung disease that usually first manifests in adulthood and gets worse over time. It frequently manifests as coughing, sputum production, and persistent shortness of breath, particularly during the winter. Although smoking is a common cause, other variables, such as exposure to environmental irritants or secondhand smoke, as well as family history, may also be involved. A worsening of these symptoms, such as increased coughing and shortness of breath, is known as an acute flare-up (exacerbation)[7].

EPIDEMIOLOGY

Smokers and people over 40 are more likely to have COPD. It is currently the third most prevalent cause of illness and mortality globally, and prevalence rises with age. Around 3.2 million people died from COPD globally in 2015, while the prevalence of the disease was 174 million. However, because COPD8 is underdiagnosed, the prevalence is probably underestimated[8].

It is more common among those who are exposed to tobacco smoke and other airborne contaminants. However, with a wide prevalence variation estimated between 3% and 21%, chronic obstructive pulmonary disease is frequently misdiagnosed[9].

ETIOLOGY

Long-term exposure to dangerous particles or gases is the cause of COPD. Globally, cigarette smoking is the leading cause of COPD. Alpha-1 antitrypsin deficiency (AATD), environmental and occupational exposures, and second and smoke are possible additional reasons both high levels of particulate matter and high doses of pesticides are associated with an increased prevalence of COPD [10]. Oxidative stress and an imbalance in proteases and ant proteases, especially in individuals with alpha-1 antitrypsin deficiency, are also part of the pathogenesis of COPD [11]. These processes may have their origins in childhood, adolescence, pregnancy, and delivery. For instance, there is a positive correlation between adult FEV_1 and birth weight. When predicting lung function in maturity, early disadvantages can be just as significant as excessive smoking [12].

PATHOPHYSIOLOGY OF COPD

(COPD) is caused by chronic airway inflammation, which thickens the walls of the airways, increases mucus production, and eventually changes the structure of the lungs permanently [13].

In this process, an aberrant healing response is triggered by repeated injury to lung tissue. The tissue surrounding the air sacs gradually thickens and scars as a result of the body producing an excessive amount of connective tissue. Because of this stiffness, it is more difficult for oxygen to enter the bloodstream and for the lungs to expand. Although the reason is frequently unknown (idiopathic), autoimmune illnesses, environmental exposures, and specific drugs may also be implicated [14].

The bronchial tree, a system of increasingly tiny tubules that terminate in alveolar sacs, is found in the spongy lungs. Numerous immune cells are part of the lungs' natural defence mechanism, which helps them fend off intruders and recover from injuries. The cilia-lined bronchial wall barrier, which is coated in mucus from goblet cells, is an essential component of this defence. Mucus and any trapped foreign particles are continuously swept out of the lungs by the motion of the cilia [15].

Both the innate and adaptive immune systems are activated when dangerous irritants enter the lungs' air sacs, or alveoli. In response to this inflammation, macrophages and alveolar epithelial cells release matrix metalloproteinases and elastase, among other damaging enzymes, along with regulatory factors [16].

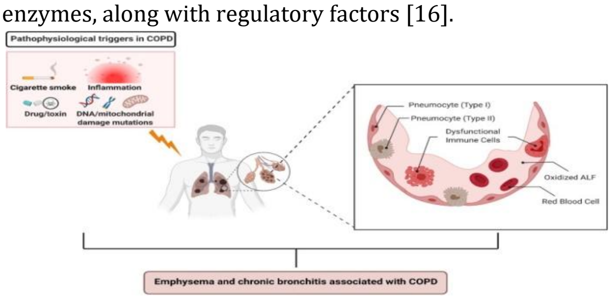

Fig 02: Diagram illustrating the alveolus in lung tissue and the pathogenesis of COPD

RISK FACTOR

The existence of COPD in people who have never smoked1 reminded us of a number of risk factors associated with COPD, even though tobacco use is the primary cause and most significant risk factor for the disease [17].

Internal risk factors, such as genetic predisposition, damaged airways from prenatal maternal smoke exposure, or childhood infections, may interact additively with external risk factors, such as secondary and tertiary smoking, occupational exposure to dust, noxious fumes and indoor air pollution from burning biomass fuels, and outdoor air pollution, to increase the incidence of COPD [18].

Exposure to biomass smoke, in particular, has been linked to COPD, even though smoking is still the primary causative risk factor. One pertinent topic from a therapeutic perspective is how to assess the exposure's severity. We have agreed to use pack-years as a way to quantify the severity of this exposure when it comes to tobacco. A comparable metric, known as the biomass index and expressed in hours-years, was introduced for biomass smoke in the early 1990s [19].

According to these scientists, women must have a biomass exposure index threshold of 60 hours annually in order to be at a high risk of acquiring chronic bronchitis. Furthermore, this biomass-associated COPD seems to show clinically differently than tobacco-associated COPD. With less emphysema but greater air trapping than tobacco smoke exposure, biomass smoke COPD is linked to its own pathogenetic process, indicating an airway-predominant phenotype [20].

CONVENTIONAL DEVICES USED IN COPD MANAGEMENT

Pressurized Metered Dose Inhalers (PMDIS)

Although the first handheld inhaler was created in 1948 by laboratories, the 1955 invention of compact, portable pressurized metered-dose inhalers (PMDIS) marked a substantial advancement in inhaler technology and allowed for efficient and dependable drug delivery [21].

Patients sometimes struggle to learn how to use pressurized metered-dose inhalers (PMDIS), despite the fact that they are a helpful tool for delivering medication straight to the lungs. Using a spacer or holding chamber helps streamline the procedure, but if it is not used correctly or is not cleaned, the patient may receive less medication [22].

Dry Powder Inhalers (DPIS)

Even though many adults find dry powder inhalers (DPIS) easier to use than pressurized metered-dose inhalers (PMDIS), the variety of DPI designs-such as self-contained blister packs and devices that require manual capsule loading-can cause confusion and result in insufficient medication[23].

Nebulizers

Nebulizers are ideal for patients who have trouble using portable inhalers because of their poor coordination, such as elderly people or young children. Because of their size, cost, length of treatment, and the time-consuming cleaning required to prevent infection, they are a worse choice for the majority of other patients [24].

Wearable and Digital Monitoring Devices

8.1. Remote patient monitoring and wearables in COPD

According to a 2012 study by Yanez et al., remote patient monitoring (rpm) can successfully identify a rise in respiratory rate in patients with COPD at home, frequently days before a severe exacerbation necessitating hospitalization. One of the key findings for the contemporary development of the technology for (COPD) management was the ability to recognize these early warning indicators, which offers a critical window for action [25].

A 2015 study by et al. discovered that exacerbations of COPD could be predicted by daily changes in respiratory rate (RR) measured by home non-invasive ventilation (NIV) equipment. When the RR was excessively high for at least two days throughout a five-day period, the probability of exacerbation rose. There were sixty-four patients in this "proof-of-concept" research [26].

According to studies, outpatients with COPD can have their respiratory rate (RR) properly measured using wearable accelerometers and chest bands, which perform similarly to more conventional techniques. These sensors are sensitive enough to identify increases in RR before a subsequent exacerbation and drops in RR following one [27].

According to a 2018 study, daily remote lung function monitoring may be a useful tool for older people with COPD, which could result in fewer hospital stays, decreased medical expenses, and an enhanced quality of life. One of its main advantages is that, unlike patients, they may do it independently and consistently at home without the assistance of a respiratory therapist[28].

In addition to proving the acceptability, tolerability, and usefulness of remote lung monitoring using in older patients with COPD with cardiac comorbidities, these hypothesis-generating secondary outcomes also advanced the field of RPM in more advanced forms of COPD, despite possibly being underpowered by a small number of events (hospitalizations) [29].

Emerging artificial intelligence and machine learning applications

A computer system that demonstrates human-like intelligence is referred to as artificial intelligence (AI), and machine learning is a subset of AI that uses statistical techniques to learn from data and perform particular tasks [30].

Processing large physiological datasets is a good fit for ai/ml techniques because of their capacity to optimize performance on their own. As a result, current remote patient monitoring has begun to use AI/ML [31].

RESPIRATORY ASSIST AND SUPPORT DEVICES

Non-Invasive Ventilation (NIV) and Portable Oxygen Concentrators

A breathing assistance device called non-invasive ventilation (NIV) uses a mask or helmet to supply air without the need for a tube in the windpipe. In contrast to CPAP, which employs a single, constant pressure, it frequently modifies the pressure as the breathing cycle progresses, alternating between inhalation and exhalation. NIV can assist increase gas exchange and lessen breathing effort in both acute and chronic respiratory failure[32].

Because it lacks an inspiratory pressure component, continuous positive airway pressure (CPAP) does not offer the full ventilation support of non-invasive ventilation (NIV), even if it aids in oxygenation and maintains airways open. Consequently, CPAP is occasionally utilized in situations that are simultaneously treated with NIV[33].

For acute respiratory failure, particularly in patients with chronic obstructive pulmonary disease (COPD), non-invasive ventilation (NIV) is a breathing support technique that eliminates the need for invasive ventilation and its associated consequences. Long-term use of it is also possible for chronic illnesses that impair a person's ability to breathe on their own[34].

Fig 03: Portable oxygen concentrators

Single Inhaler Triple-Drug Therapy

The ability to integrate three drugs into a single inhaler is a recent breakthrough. It combines LAMA with fixed ICS/LABA, or the other way around. This approach maintained a high degree of safety and health while preventing medication overuse and exacerbation risk. Additionally, it showed better lung function than either solo LAMA therapy or ICS/LABA [35].

Fig 04: New inhaler that combines three drug together

DIAGNOSIS

Accurate and early diagnosis of chronic obstructive pulmonary disease (COPD) is essential to slow progression, reduce exacerbations, and personalize therapy. Traditional diagnostic workup-clinical assessment plus spirometry demonstrating persistent airflow limitation (post-bronchodilator FEV1/FVC < 0.70)-remains the backbone of COPD identification, but substantial technological progress during the last few years has broadened the diagnostic toolbox. New and improved point-of-care devices, digital biomarkers, breath-based sensors, and AI-driven analytics are all improving access, sensitivity, and longitudinal monitoring of disease [36].

Spirometry and portable spirometers

Spirometry continues to be the gold standard for confirming airway obstruction, but availability and quality control have limited its use in primary care and community screening. The proliferation of validated portable and wireless spirometers has changed this dynamic: recent comparative studies show strong agreement between portable devices and laboratory spirometers for key indices (FEV1, FVC) and for detecting abnormal pulmonary function, enabling reliable community-based screening and telehealth use. These handheld devices often pair with smartphone apps that guide users through maneuvers, enforce quality checks, and transmit results to clinicians for remote interpretation-facilitating earlier case finding and follow-up outside specialized clinics [37].

Oscillometry and small-airway assessment

Impulse oscillometry (IOS) and related forced oscillation techniques offer effort-independent measurements of airway resistance and reactance, making them particularly useful in patients unable to perform repeatable spirometry (elderly, very symptomatic, or frail patients). Recent work has explored IOS as a complementary diagnostic tool that can detect small-airway dysfunction earlier than conventional spirometry, and several device vendors now offer clinically validated oscillometry instruments suitable for outpatient or point-of-care deployment [38].

High-resolution and low-dose CT imaging provide structural detail that complements functional testing, revealing airway wall thickening, emphysema distribution, and small-airway loss. Advances in quantitative CT processing now allow automated segmentation and volumetric emphysema scoring, which can help phenotype COPD, predict progression, and support differential diagnosis. Integration of CT metrics into diagnostic pathways is increasing, particularly when clinical and spirometric results are discordant [39].

Breath analysis and volatile biomarkers (Nose, EBC)

Breath analysis technologies-ranging from gas chromatography–mass spectrometry (GC-MS) to compact electronic noses (Nose)-detect volatile organic compounds (VOCs) and other exhaled biomarkers associated with airway inflammation, infection, and oxidation. Recent reviews and prospective studies report promising accuracy for discriminating COPD from other respiratory conditions and for identifying exacerbation risk signatures. The major advantages are noninvasiveness, potential for real-time or near-real-time measurements, and suitability for continuous or at-home monitoring when incorporated into wearable or mask-based platforms. Notably, integrated “smart-mask” prototypes and portable condensate collectors have demonstrated feasibility in detecting breath markers related to airway inflammation, opening the door to low-cost, wearable diagnostic screening [40].

Exhaled breath condensate and point-of-care assays

Exhaled breath condensate (EBC) collection and point-of-care assays for biomarkers (nitrites/nitrates, pH, leukotrienes) have improved through miniaturised condensers and stabilization chemistries. Although still largely investigational, optimized EBC sampling integrated with rapid readouts may complement other diagnostics by providing biochemical evidence of airway inflammation or oxidative stress [41].

Pulse oximetry, home oximetry and remote patient monitoring

Pulse oximetry remains a basic diagnostic adjunct to assess oxygenation and guide supplemental oxygen decisions. Recent evaluations of home oximetry-particularly in integrated remote patient monitoring programs-show utility in tracking disease stability and detecting early deterioration, although device accuracy and appropriate clinical thresholds require local validation. RPM platforms that combine oximetry with symptom apps, inhaler usage logs, and spirometry data are increasingly tested for early detection of exacerbations and for triaging care [42].

Artificial intelligence and machine learning integration

AI and machine learning are being applied to multi-modal diagnostic inputs-spirometry traces, oscillometry signals, CT radiomics, and breath VOC patterns-to improve classification, phenotype identification, and predictive accuracy. Algorithms trained on large, labeled datasets can enhance screening sensitivity (flagging borderline spirometry), reduce false negatives, and stratify patients by risk of progression or exacerbation. The combination of low-cost sensors plus cloud-based analytics enables scalable screening programs and decision support for non-specialist clinicians [43].

Practical implications and limitations

These technological advances substantially widen opportunities for earlier diagnosis, decentralized screening, and continuous monitoring. Portable spirometers and wearable breath sensors lower access barriers; oscillometry offers an alternative for patients who can't perform spirometry; and AI analytics can synthesize multi-source data for better case finding. Nonetheless, challenges remain: standardization and external validation of novel devices across diverse populations, regulatory approval pathways, data privacy and interoperability, and the need for cost-effectiveness evidence to support widespread adoption. Clinical integration will require clear referral pathways, quality assurance, and clinician training to interpret new types of data. This is the mater [44].

TREATMENT IN DEVICES FOR CHRONIC OBSTRUCTIVE PULMONARY DISEASE (COPD)

The progressive lung disease known as chronic obstructive pulmonary disease (COPD) causes airflow obstruction, which makes breathing challenging. It covers conditions including chronic bronchitis and emphysema. Medical devices are equally vital in supporting treatment, improving lung function, properly administering medications, and improving patients' quality of life, even though medications are crucial in managing COPD [45].

As technology has advanced over time, numerous devices have been created to address various elements of COPD, ranging from long-term oxygen support to inhalation therapy. These devices can be used to monitor health status, help with breathing, improve lung efficiency, or assist with medicine delivery. The most popular tools for treating COPD are described in this article [52].

Inhalers

The most popular and necessary tools for delivering drugs straight into the lungs are inhalers. They are made to deliver corticosteroids, bronchodilators, or a mix of the two. Inhalers are divided into a number of categories according on how they work [46]

a. metered-dose inhalers or MDIs,

MDIs are portable devices that, when activated, deliver a predetermined quantity of medication as an aerosol. The drug is delivered straight to the lungs when patients inhale the aerosol through their mouths. It is necessary to coordinate actuation and inhalation, which some people may find difficult. MDIs are therefore frequently used in conjunction with spacers.

b. soft mist inhalers or SMIs,

SMIs provide a slow-moving mist that facilitates drug inhalation. Patients who struggle with coordination or have weaker lungs can benefit from them. Additionally, reduced medicine loss and deeper lung penetration are made possible by the gentle mist

Spacers and Holding Chambers

Add-on devices called spacers are used in conjunction with MDIs to improve the administration of medications. The discharged medication is held in place by these tubular attachments, giving the patient additional time to thoroughly inhale it. This lessens the requirement for exact coordination and makes sure that more medicine gets to the lungs instead of the mouth or throat. Though they contain one-way valves that keep exhaled air from entering, holding chambers resemble spacers. Patients who are elderly or have trouble using inhalers will find these gadgets extremely useful[47]

Nebulizers

Nebulizers are machines that turn liquid drugs into a fine mist that can be inhaled using a mouthpiece or mask. They are frequently utilize in more severe cases of COPD or when a patient's frailty or lack of coordination prevents them from using inhalers successfully[48].

Nebulizers are especially helpful during exacerbations and enable longer, more comfortable inhalation sessions.

Nebulizers come in three primary varieties

- **Jet nebulizers:** These devices create a mist out of liquid medication by using compressed air.
- **Ultrasonic nebulizers:** Produce the mist by high-frequency vibrations.

Mesh nebulizers: These are more portable and quieter than jet kinds; they produce an aerosol using a vibrating mesh. Nebulizers are frequently used in hospitals and homes to administer bronchodilators, corticosteroids, and antibiotics despite their size and cleaning requirements.

Oxygen Therapy Devices

In advanced COPD, the lungs' incapacity to absorb adequate oxygen can lead to chronic hypoxemia. Long-term oxygen therapy (LTOT) helps maintain proper oxygen levels, reduces problems, and improves survival. The following tools are utilize in oxygen therapy: a. Oxygen Concentrators [49].

The patient is given concentrated oxygen by these machines, which also remove nitrogen from the air. Home oxygen concentrators are widely used and provide a consistent supply. Patients have more freedom and mobility while using portable oxygen concentrators that run on batteries.

Oxygen cylinders

For use at home or on the go, compressed oxygen can be kept in oxygen cylinders. They are usually utilize as concentrator backups or for short-term oxygen needs. Although the size and portability of these tanks varies, they must be regularly refilled.

Systems of liquid oxygen

Liquid oxygen systems store cold, liquefied oxygen. Because these devices are more portable and provide higher oxygen flow rates than traditional cylinders, they are suitable for patients with high oxygen needs.

Non-Invasive Ventilation (NIV) Devices

Non-invasive ventilation may be required in patients with severe COPD, particularly in cases of respiratory failure or acute exacerbations. Intubation is not necessary while using NIV to help breathing. BiPAP, or bilevel positive airway pressure, is the most widely utilize type.

By using a mask to supply pressurized air, NIV devices help maintain open airways and enhance the exchange of carbon dioxide and oxygen. For patients with chronic hypercapnia (high blood CO_2 levels), regular use at night can assist enhance sleep and lessen daytime weariness.

Positive Expiratory Pressure (PEP) Devices

Airway clearance therapy uses PEP devices. By producing resistance during exhalation, these portable devices aid in maintaining open airways and promoting mucus clearance. PEP therapy can improve lung function and lower the incidence of infections in individuals with COPD by increasing ventilation and decreasing airway blockage.

PEP devices come in a variety of shapes, such as oscillatory devices that further release mucus by adding vibrations during exhale. These gadgets are easy to use, portable, and may be incorporated into daily activities.

High-Flow Nasal Cannula (HFNC) Systems

Through the nasal prongs, HFNC systems provide high flow rates of warmed, humidified oxygen. In hospital settings, they are being utilize more frequently for patients who are having severe exacerbations of their COPD. Without the need for a tight-sealing mask, the high flow helps to enhance oxygenation, lessen breathing effort, and wash out CO_2 from the airways.

Some HFNC systems are currently being modified for home usage in a small number of patients under strict physician monitoring, despite being largely hospital-based.

Monitoring Devices and Smart Inhalers

The use of technology in the treatment of COPD is growing. Sensors included into smart inhalers monitor inhaler usage and transmit information to smartphone apps. These tools assist in tracking treatment compliance and identifying early exacerbation indicators. Furthermore, wearable technology that tracks heart rate, respiratory rate, and oxygen saturation (SPO_2) is growing in popularity. Personalized care and prompt actions are made possible by ongoing monitoring [50].

CONCLUSION

Effective management of COPD necessitates the use of medical devices that are appropriate for each patient's condition and capabilities, in addition to medicine. In order to manage symptoms, enhance lung function, and improve quality of life, inhalers, nebulizers, oxygen treatment systems, and ventilatory support devices are all necessary. Newer gadgets like smart inhalers and remote monitoring tools are revolutionizing the way patients and medical professionals treat this chronic illness as technology advances. When utilize appropriately, a combination of gadgets.

FUNDING

Nil

ACKNOWLEDGEMENT

Not Declared.

CONFLICT OF INTEREST

Nil

INFORMED CONSENT

Not applicable

ETHICAL STATEMENT

Not Applicable.

AUTHOR CONTRIBUTION

All authors contributed equally towards the process.

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