Advances and Prospects of Internet of Things Technology in Chronic Obstructive Pulmonary Disease Management: Postprint

Authors: Pan Zihan, Li Shurun, Chen Yahong, Yahong Chen

Date: 2023-08-29T00:00:00+00:00

Abstract

In recent years, Internet of Things (IoT) technology has developed extremely rapidly and has been widely applied in the medical field. Chronic Obstructive Pulmonary Disease (hereinafter referred to as COPD) is the most common chronic respiratory disease in China, and how to utilize IoT technology to improve clinical practice in COPD management is worth exploring. The authors summarize the research progress of IoT technology in COPD management both domestically and internationally. Through literature review, it was found that current application research of IoT in COPD management remains in the exploratory stage, lacking high-quality, large-sample studies. Future studies need to conduct more systematic real-world application evaluations of mature technological models or products, particularly regarding their impact on patients' long-term clinical outcomes and quality of life, as well as health economic evaluations. Product design should align with the characteristics of COPD and the features of the target user population, and understanding user experience, perceptions, or attitudes through qualitative research is also noteworthy.

Full Text

Research Progress and Prospects of Internet of Things Technology in Chronic Obstructive Pulmonary Disease Management

PAN Zihan[1,2], LI Shurun[1], CHEN Yahong[1]*

[1]Department of Pulmonary and Critical Care Medicine, Peking University Third Hospital, Beijing 100191, China
[2]Department of General Practice, Peking University First Hospital, Beijing 100034, China

Corresponding author: CHEN Yahong, Professor/Doctoral supervisor; Email: chenyahong@vip.sina.com

Abstract

Internet of Things (IoT) technology has developed rapidly in recent years and found widespread application in the medical field. Chronic obstructive pulmonary disease (COPD) is one of the most common chronic respiratory diseases in China, making it worthwhile to explore how IoT can improve clinical COPD management practices.

Through a review of the literature, we summarized research progress on IoT technology in COPD management both domestically and internationally. We found that current research on IoT applications in COPD management remains in the exploratory stage, lacking high-quality, large-sample studies. Future research should conduct systematic real-world evaluations of mature models or products, particularly regarding their impact on long-term patient outcomes, quality of life, and health economics. Product design should align with COPD disease characteristics and user demographics, while qualitative research investigating user experiences, perceptions, and attitudes toward such products also warrants attention.

Keywords: Pulmonary disease, chronic obstructive; Internet of things; Disease management; Review

---

Internet of Things (IoT) technology represents an important component of new-generation information technology, essentially an "internet of interconnected things" that extends user connectivity to enable information exchange and communication between any objects [1]. As IoT has become increasingly prevalent in medicine, the concept of the Internet of Medical Things (IoMT) has emerged, connecting healthcare workers, patients, and various medical devices and facilities intelligently and conveniently through IoT and communication technologies. This integration comprehensively supports automatic identification, positioning, collection, tracking, management, and sharing of medical data, facilitating intelligent healthcare and item management [2].

Health information collected through IoT follows specific pathways: IoT hardware uploads collected data (including automatically acquired and user-entered data) to cloud platforms, which utilize cloud computing capabilities for storage, processing, and analysis before sending feedback to users' mobile phones, computers, and other terminals [3] [Figure 1: see original paper].

Given its efficient, continuous, and convenient characteristics, IoT offers substantial advantages in chronic disease management, with related research increasing annually. According to statistics, 322 foreign-language articles on IoT applications in chronic diseases were published in the Web of Science database between 1999 and 2020. After the first article on this topic appeared in 1999, publication numbers rose each year, peaking at 47 articles in 2019, demonstrating that IoT applications in chronic diseases have become a research hotspot [3]. During the COVID-19 pandemic, IoT played a particularly important role, enabling tracking of high-risk populations, monitoring of quarantined individuals, large-scale screening in general populations, and epidemic prediction. By enabling remote data collection and real-time transmission, IoT helped reduce pandemic spread to some extent [4-5] and facilitated effective pandemic response. The COVID-19 pandemic also accelerated IoT development, particularly for wearable devices [6-7].

Chronic obstructive pulmonary disease (COPD) is a common respiratory disease worldwide. WHO data indicate that 384 million people globally suffer from COPD, with 3.17 million deaths annually [8]. COPD is also the most common chronic respiratory disease in China, affecting 99 million people and imposing a heavy burden on both families and the nation [9]. How to leverage IoT to improve COPD management has become a key research question both domestically and internationally. As early as 2013, scholars proposed constructing an IoT-based comprehensive COPD management system using mobile phones, sensors, and cloud servers [10]. SWOT analysis revealed that IoT-based healthcare facilitates standardized, comprehensive, and intelligent COPD management, enabling both physicians and patients to obtain needed information and improving communication efficiency. Additionally, remote medical systems can connect medical institutions at all levels, channeling high-quality medical resources to primary care facilities and achieving vertical integration of healthcare resources [11]. This demonstrates IoT' s substantial potential value in COPD management. This article summarizes domestic and international research and applications of IoT in COPD management to understand the current research status, identify advantages, and summarize challenges and difficulties, providing insights for future research and applications.

1. Search Strategy

We searched PubMed, Wanfang, CNKI, and other databases from inception to April 30, 2023. Chinese search terms included: Internet of Things, internet, internet plus, telemedicine, remote management, wearable devices, artificial intelligence, COPD, chronic obstructive pulmonary disease. English search terms included: Internet of Things Technology, IoT, wearable device, Tele-health, Telemedicine, AI, artificial intelligence, COPD, Chronic Obstructive Pulmonary Disease. Inclusion criteria comprised studies on IoT applications in COPD management. Exclusion criteria included: irrelevant topics, unavailable full texts, and studies that mentioned "Internet of Things" without actually applying true IoT technology.

From Chinese databases (CNKI, Wanfang), we retrieved 243 articles, excluding 65 duplicates, 83 irrelevant articles, 19 dissertations, 38 reviews, 4 scientific achievements, 7 conference papers, 11 non-academic journal articles, and 7 non-IoT articles, leaving 9 articles for analysis. From English databases (PubMed), we retrieved 3,117 articles, excluding 8 duplicates, 3,038 irrelevant articles, 24 reviews, 2 commentaries, 2 qualitative studies, 1 guideline, 7 articles without full text, 3 study protocols, and 6 non-IoT articles, leaving 26 articles for analysis (16 on device development and 10 on clinical application). The literature search results are visualized in Supplementary Table 1 .

2. Applications of IoT in COPD Management

2.1 Disease Screening China has a large COPD patient population, and screening is recommended. Studies have validated the accuracy of screening tools such as the COPD Diagnostic Questionnaire (CDQ), CAPTURE questionnaire, and portable spirometers [12], but these tools suffer from low utilization and suboptimal screening efficiency. How to identify COPD patients more efficiently represents a domestic research priority. In a mobile internet information platform established in a Shanghai community, a COPD screening questionnaire was embedded, identifying 218 COPD patients and automatically grading disease severity while providing treatment guidance information [13]. This application demonstrates how IoT platforms can improve screening tool accessibility, expand screening coverage, and enhance efficiency. Other studies have used IoT to collect physiological indicators (such as activity levels, heart rate, respiratory rate, and oxygen saturation) for COPD screening, providing more objective data [14-16]. However, the number of physiological indicators directly related to COPD that can be monitored remains limited, and the correlation between these indicators and COPD requires further investigation.

2.2 Condition Monitoring Effective disease monitoring constitutes an essential component of COPD management. IoT provides convenient conditions for continuous patient follow-up and treatment adjustment while promoting self-monitoring and improving treatment adherence [17]. A small domestic randomized controlled trial used Bluetooth-enabled devices for pulmonary function monitoring and breathing exercises in stable COPD patients, with data transmitted in real-time to mobile apps and WeChat mini-programs. The system also monitored medication usage (timing, frequency, adverse reactions), while wearable hardware such as respiratory trainers, blood pressure monitors, and pulse oximeters continuously monitored physiological indicators and automatically transmitted data to cloud platforms. After six months of follow-up, all 16 patients in the IoT management group maintained standardized treatment, compared to only 8 of 15 patients in the conventional care group, with one patient discontinuing treatment independently [18]. Although this study demonstrated IoT' s positive impact on adherence, the small sample size and limited quantitative measures reduced study validity.

Acute exacerbation represents a critical aspect of COPD management. Establishing exacerbation prediction models using IoT-collected data and machine learning techniques constitutes a common research focus. In a small-sample study from Taiwan, researchers collected patients' home lifestyle data, environmental parameters, and symptoms using wearable devices, air quality sensors, and mobile apps to build a COPD exacerbation prediction model. The model achieved 92.1% accuracy in predicting exacerbation events within one week, with 94.0% sensitivity, 90.4% specificity, and an area under the ROC curve (AUC) exceeding 90% [19]. However, the study only collected four months of patient data, providing insufficient evidence for model stability, and lacked external validation and real-world clinical application evidence. Changes in lung sounds may indicate exacerbations, and IoT can help collect such subtle clinical information. FERNANDEZ-GRANERO et al. [20] used a stethoscope with remote auscultation capabilities to monitor lung sound changes, predicting 75.8% of exacerbation events an average of (5.0$±$1.9) days in advance, though only 16 patients participated without large-scale application.

2.3 Pulmonary Function Monitoring Pulmonary function monitoring is crucial in COPD management, and portable spirometer intelligence represents the main development trend under IoT. China has developed portable spirometers with intelligent software that can transmit data to computers or mobile phones via network or USB connections, or directly to cloud servers. Validation studies have demonstrated high consistency between these devices' parameters and diagnostic spirometry results, making them suitable for COPD screening [21]. These portable spirometers have shown good practicality in large-scale populations. Between 2017 and 2018, nearly 90,000 residents in a Chinese region underwent pulmonary function testing using this device, with 61,624 residents providing acceptable data (70% efficiency), effectively detecting obstructive, restrictive, mixed, and small airway ventilation dysfunction and greatly improving screening efficiency [22]. Portable spirometers with remote data transmission also provide convenience for patients in remote areas. Bosnian researchers developed a similar Bluetooth-enabled portable spirometer, achieving 97.3% accuracy compared to manual diagnosis when validated in 780 COPD and asthma patients from remote areas [23]. Such products are relatively mature and suitable for promotion in economically underdeveloped regions to improve diagnosis of chronic airway diseases.

Mobile phones are the most commonly used mobile devices. Korean researchers developed a mobile phone-based pulmonary function testing application. In this study, users could perform pulmonary function tests through a remote monitoring app, cloud platform, and smartphone microphone without external devices. During testing, the phone displayed flow-volume curves and measured forced expiratory volume in one second (FEV1), forced vital capacity (FVC), peak expiratory flow (PEF), and FEV1/FVC ratio, with data uploaded to the cloud platform for remote monitoring. This application allowed patients to measure pulmonary function freely without time or space constraints while enabling physicians to monitor patients' lung function in real-time [24]. Currently, the application remains in the development stage, having only been validated in small healthy populations without widespread clinical application. The measurement accuracy remains uncertain and requires consistency comparison with diagnostic spirometry results. Notably, pulmonary function interpretation requires both numerical values and flow-volume curves, particularly the curves, which are primary quality indicators. While portable spirometers demonstrated good practicality in the aforementioned studies, quality control of graphical data received little attention. Graphical interpretation represents a key technical issue requiring attention in future intelligent spirometer development.

2.4 Respiratory Rehabilitation Guidance Respiratory rehabilitation is an important non-pharmacological treatment for COPD, but implementation in China remains suboptimal due to resource constraints, with low penetration rates and most programs limited to large tertiary hospitals [25]. Studies show that home-based rehabilitation is equally effective as facility-based training [26-27]. IoT provides technical support for respiratory rehabilitation implementation, particularly for home-based programs, helping patients benefit from rehabilitation training. Systematic reviews demonstrate that mobile smart devices can promote physical activity, improve quality of life and self-management capabilities, enhance rehabilitation adherence, and even facilitate early exacerbation identification, thereby reducing rehospitalization rates and medical costs [28]. However, this review included only foreign studies, reflecting the current state of respiratory rehabilitation implementation in China. High-quality domestic research on IoT applications in respiratory rehabilitation is urgently needed, as current studies are small-scale exploratory trials.

In a study of COPD patients admitted to a Chinese tertiary hospital, the IoT rehabilitation group used IoT-enabled respiratory training equipment. Patients logged into personal accounts via smartphone apps or mini-programs and connected rehabilitation devices via Bluetooth or wireless networks. The apps allowed patients to select training types and intensity based on rehabilitation protocols, while the equipment collected pulmonary function data, training frequency, and effectiveness information transmitted via Bluetooth or wireless networks. Physicians could remotely monitor rehabilitation progress and issue rehabilitation prescriptions, which patients then implemented at home. After four weeks of training, maximum inspiratory pressure (MIP), an indicator of maximum inspiratory muscle strength, improved in both groups but increased more significantly in the IoT rehabilitation group (6.43 vs. 5.06). In terms of daily living capacity, activities of daily living (ADL) scores improved more markedly in the IoT group (22.61 vs. 12.08). Regarding rehabilitation adherence, 22.9% (11/48) of patients in the conventional rehabilitation group showed fair or poor adherence compared to only 2% (1/48) in the IoT group [29]. The rehabilitation equipment used in this study demonstrated certain intelligence, automatically collecting and transmitting patient data to help healthcare staff comprehensively understand patient progress. However, high development costs raise questions about applicability to broader community populations, requiring future validation.

Wearable devices offer good accessibility and have applications in respiratory rehabilitation. In a study using wearable devices to guide elderly COPD patients through pulmonary rehabilitation, patients wore devices daily to record and upload dietary habits, home oxygen therapy data, and rehabilitation training implementation, receiving monthly follow-up reports. After 12 months, patients showed significant improvements in pulmonary function, COPD Assessment Test (CAT) scores, modified Medical Research Council (mMRC) dyspnea scores, and quality of life [30]. However, this study required patients to actively enter information into wearable devices and manually upload data, compromising information accuracy and requiring daily monitoring, review, and interpretation by healthcare staff. The insufficient device intelligence still relied on intensive human resources. Since COPD patients are predominantly elderly with varying abilities to use wearable devices, manual data entry may create burdens leading to device abandonment. Active monitoring and automatic health information upload may better ensure effectiveness and data accuracy.

While diverse IoT devices show feasibility for respiratory rehabilitation, existing studies have been conducted in tertiary hospital patients with small samples and short observation periods. Large-scale, long-term clinical trials are needed to fully validate the effectiveness and cost-benefit of various device types. Given China’ s suboptimal respiratory rehabilitation implementation, domestic research on IoT applications is scarce, particularly high-quality studies, leaving substantial room for exploration. In 2021, China published guidelines for respiratory rehabilitation based on IoT [31], aiming to promote respiratory rehabilitation implementation and maximize its therapeutic role in COPD.

2.5 Medication Guidance Inhaled medication represents an important component of COPD treatment. Smart inhaler devices have attracted considerable attention, using sensors attached to or integrated into inhalers that primarily connect via Bluetooth to mobile device applications. These devices not only remind patients to use inhalers but also provide personalized feedback based on usage timing and inhalation technique. This information helps detect and correct patient medication habits while guiding physicians in adjusting treatment [32-33]. Initially developed to monitor medication adherence, these devices have shown improved adherence, reduced exacerbation frequency, and improved lung function in COPD and asthma patients [34-36]. As device development becomes more sophisticated, their applications have expanded. A U.S. study installed sensors on short-acting bronchodilator (albuterol) inhalers to collect usage information, identifying characteristics and usage patterns in frequent albuterol users and providing reference information for patient assessment and precision treatment [37].

However, despite technological advances reducing costs, price remains a consideration, with most clinical studies conducted in developed countries. Due to high development costs, these products have mostly been tested in small samples, and their application effectiveness requires validation in larger populations. Although some studies demonstrate good cost-effectiveness for smart inhalers, evidence regarding long-term cost-effectiveness in daily patient life remains lacking [38]. Additionally, since these devices typically require smartphone connectivity, patients need smartphones and operational skills, which may limit promotion among predominantly elderly COPD patients.

2.6 Non-invasive Ventilator Therapy Non-invasive ventilation is an effective COPD treatment, particularly for patients with hypercapnia. Integrating IoT with non-invasive ventilators promotes their application in COPD management. IoT-based home non-invasive ventilators enable remote monitoring of gas exchange and ventilation parameter adjustment, reducing hospitalization time for ventilator titration [39-41]. A Chinese COPD study showed that after six months of using such ventilators, patients demonstrated improved FEV1 and FVC, reduced mMRC and CAT scores, increased superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) levels (indicators related to oxidative stress), and decreased serum lipid peroxide (LPO) and malondialdehyde (MDA) levels. Additionally, rehospitalization and acute exacerbation rates decreased [42].

Adherence is a crucial factor affecting non-invasive ventilation efficacy. Research conclusions on remote monitoring of ventilator adherence vary between domestic and international studies. Chinese research shows that COPD patients using IoT-based non-invasive ventilators had significantly higher usage days and duration than conventional ventilator patients, demonstrating improved adherence [43]. However, foreign studies indicate that while remote ventilator monitoring reduces treatment costs and improves survival, it does not improve adherence [44-45]. Other foreign studies show positive effects of remote non-invasive ventilators on adherence [46-47]. These studies were conducted in obstructive sleep apnea (OSA) patients, a common COPD comorbidity, but differences in treatment dependence between populations may contribute to conflicting results. Currently, few studies have examined IoT-based non-invasive ventilators in COPD patients. Although OSA studies provide some reference value, large-scale multicenter studies are needed to validate application effects in COPD patients, particularly regarding safety, efficacy, and health economics of remote ventilator monitoring.

2.7 Remote COPD Management A 2012 Cochrane systematic review and meta-analysis examined remote healthcare effectiveness in COPD management, finding that telemedicine did not improve quality of life or reduce mortality risk but decreased emergency visits and hospitalization risk [48]. As IoT has evolved, clinical evidence has shown subtle changes. A 2018 Spanish RCT on COPD remote management had patients self-measure blood pressure, oxygen saturation, heart rate, and vital capacity at home while wearable devices collected respiratory rate and oxygen usage data, all transmitted via IoT. After 12 months of follow-up, all-cause mortality was similar between IoT remote management and conventional management groups (12 vs. 13 cases), with no significant reduction in emergency visits or hospitalizations (60%

vs. 53.5%, P>0.05), differing from previous research conclusions. Regarding healthcare resource utilization, remote management costs were significantly lower than conventional management (€7,912 vs. €8,918). Although differences were not statistically significant, hospitalization duration and ICU treatment time were markedly shorter in the remote management group [(18.9$±16.0)*daysand*(6.0±4.6)*daysvs.*(22.4±19.5)*daysand*(13.3±$11.1) days] [49]. As technology continues advancing, collected data will become more diverse and accurate, suggesting the need for dynamic evaluation of remote COPD management effectiveness.

2.8 Assisting in Implementation of Graded Diagnosis and Treatment Due to healthcare system differences, graded diagnosis and treatment has only received deserved attention in China in the past decade, particularly for chronic diseases like COPD where IoT provides technical support. As early as 2014, Chinese scholars proposed leveraging IoT platforms to maximize general practitioners' role in COPD management while extending specialized services from large hospitals to communities, using IoT as a medium to facilitate communication between general and specialist physicians [50]. A Shanghai community study on IoT-based COPD management connected community general practitioners with patients via terminal apps, allowing emergency communication with tertiary hospital respiratory specialists through the platform. The respiratory team could access patient information and condition updates in real-time, conducting remote consultations, referrals, or hospitalizations when necessary, forming a collaborative management model between general and respiratory specialists [51]. Although this small-scale exploratory trial did not yield quantitative results and used relatively simple IoT devices, it demonstrated that patients received standardized, professional medical guidance and treatment at community health institutions, achieving homogeneous management while saving patients' time and simplifying care processes. The study particularly demonstrated resource sharing and real-time communication between community and tertiary hospitals, providing reference value for IoT applications in COPD graded diagnosis and treatment.

Early small-scale explorations have shown IoT' s potential to provide platforms and pathways for implementing COPD graded diagnosis and treatment. As technology advances, IoT will play greater roles in this area. In Xiamen' s Haicang District, an intelligent wireless transmission cloud platform based on IoT records basic information and pulmonary function data for all study participants, enabling referral of screened moderate-to-severe airway obstruction patients through green channels to higher-level hospitals. This IoT medical technology effectively integrates regional medical information resources, laying foundations for implementing COPD graded diagnosis and treatment [52].

2.9 Application of Wearable Devices in COPD Management Using wearable devices for COPD management represents a research hotspot, primarily applied in remote monitoring, disease prediction, patient education, and consultation, collecting physiological indicators such as respiratory rate, heart rate, activity tracking, and oxygen saturation. Domestic and international studies show that wearable devices help improve clinical symptoms, pulmonary function, quality of life, and self-management capabilities while reducing medical costs, hospitalization rates and duration, mortality risk, and healthcare resource utilization [53]. However, no studies have shown that these technologies reduce acute exacerbation risk, possibly due to study populations being predominantly stable patients with short observation periods insufficient to detect exacerbation events, limiting conclusions about exacerbation management impact. Some clinical trials have used wearable devices to remotely monitor vital signs and oxygen saturation for condition assessment but achieved unsatisfactory results, likely because COPD lacks daily monitoring indicators as closely disease-related as blood pressure or blood glucose. Oxygen saturation has low sensitivity and specificity, requiring further research on more specific indicators [54]. Although numerous studies have explored wearable devices in COPD, research using these devices to inform clinical decision-making remains limited, with far fewer studies than in cardiovascular disease or diabetes, and most focusing on product development rather than clinical application.

3. Problems and Challenges in IoT-Based COPD Management

While IoT' s advantages in COPD management are evident, several problems and challenges exist.

3.1 More Device Development Studies, Fewer Clinical Application Studies, and Lack of High-Quality Research Current domestic and international research on IoT-based COPD management primarily consists of small-sample exploratory trials focusing on technical feasibility. Among the 26 included English articles, 16 focused on device development and only 10 on clinical application, indicating a gap between technological development and clinical application, with clinical implementation lagging behind. Although many product types exist, few have entered clinical research. High-quality studies are particularly lacking, especially cohort studies or RCTs. While most products demonstrate good effectiveness during development, small sample sizes limit result robustness, lacking external validation and real-world application evaluation, particularly health economics assessments. Additionally, COPD shows seasonal variation, but most studies have observation periods of only 6-12 months, some lasting just days, failing to capture seasonal disease status data comprehensively.

3.2 Inability to Guarantee Authenticity and Accuracy of Patient-Reported Information Symptom assessment is an important monitoring component in COPD management. Due to the lack of objective physiological indicators related to COPD symptoms, many studies require patients to actively complete symptom questionnaires or scales, creating risks of missed, incorrect, or omitted entries that require additional human resources for data quality monitoring [30,55]. In wearable device applications, the most common drawback is inaccurate information collection [56].

3.3 Discrepancies Between Study Populations and Target Populations
IoT has achieved ideal results in many studies, but selection bias exists regarding study populations. Mobile phones are the most common IoT devices, with most studies requiring participants to own smartphones, which are not universally available among COPD patients. One survey found that only 23% of COPD patients owned smartphones. While COPD patients generally support IoT, technical issues, lack of awareness, poor acceptance among elderly patients, and economic factors constitute major barriers to using such products [57]. Although terminal device interfaces are increasingly simplified, COPD patients are predominantly elderly with varying abilities to use smartphones and tablets. In one study using smartphones and wearable devices to monitor rehabilitation activities, 47% of patients withdrew due to difficulty operating devices [58]. A Chinese qualitative study of community-dwelling elderly COPD patients showed that due to limited smartphone operation skills, patients preferred traditional disease management models [59]. These factors affect result representativeness and limit technology promotion and population application.

3.4 Poor Data Usability Clinical workers expect collected data to be computed, analyzed, and presented in visualized forms through cloud computing capabilities. Although some wearable devices accurately collect physiological data, parameter calculation intelligence is insufficient, with most data remaining raw and requiring professionals to extract and manually interpret after verification [2,60], reducing data usability.

4. Future Prospects for IoT Application in COPD Management

In summary, IoT-based COPD management shows promise, but most research remains exploratory, lacking high-quality, large-sample studies. Future work should emphasize real-world evaluation of mature products or disease management approaches. Additional evidence is needed to clarify IoT' s impact on long-term clinical outcomes, healthcare resource utilization, and quality of life in COPD patients. Product design should align with COPD characteristics and target populations, while qualitative research should be valued to understand user experiences, perceptions, and attitudes for product optimization.

As IoT development matures, its impact on disease management models will become increasingly significant. We propose the following prospects addressing the aforementioned challenges:

4.1 Develop Application Systems or Devices Tailored to COPD Management Needs Based on COPD characteristics, long-term management and follow-up are particularly important, concerning not only routine disease assessment but also timely and effective identification of acute exacerbation events. Regarding treatment, inhaled medications are unique to COPD and require adjustment based on disease status. Additionally, symptom assessment, smoking cessation guidance, rehabilitation training, and pulmonary function testing are essential components of COPD management. However, few current IoT products integrate these comprehensive management needs. Future design should consider each aspect of COPD management to develop products aligned with disease characteristics.

4.2 Conduct Higher-Quality Clinical Studies to Systematically Evaluate Real-World Clinical Effectiveness Most current studies have validated technical feasibility. Future research should focus on evaluating implementability and effectiveness. Mature products or models can be selected for broader validation trials based on clinical needs. For example, wearable devices have considerable prospects in consumer markets, and mature wearable technologies could be introduced into clinical practice, fully integrating user needs with medical requirements. The accuracy of consumer-grade wearable devices with motion sensors that also monitor respiratory rate, heart rate, and peripheral oxygen saturation could be improved for clinical applications such as 6-minute walk test monitoring [61-62].

4.3 Emphasize Health Economics Evaluation Good feasibility is a necessary condition for technology promotion, but utility must also be evaluated from a health economics perspective. Most studies have been conducted in economically developed regions, and although products demonstrate good effectiveness, most devices have high costs. With China' s large COPD population, particularly in economically underdeveloped areas, economic benefits must be considered alongside effectiveness. Future research should prioritize products that achieve both effectiveness and cost-benefit optimization.

4.4 Improve User Experience Based on Target Population Characteristics In addition to technical effectiveness, research should emphasize user experience, deeply understanding existing problems to continuously optimize usability. Qualitative research can reveal healthcare providers' and patients' perceptions and attitudes, fully understanding IoT' s strengths and weaknesses [63] to improve research quality and product design. For COPD, where patients are predominantly elderly, understanding their perspectives, attitudes, and needs will facilitate better technology promotion.

Author Contributions: PAN Zihan conducted literature searches and drafted the manuscript; LI Shurun conducted literature searches; CHEN Yahong selected the topic, revised the manuscript, and takes responsibility for the article.

Conflict of Interest: The authors declare no conflict of interest.

References

[1] YANG Dawei, ZHANG Jing, BAI Chunxue. Research status and prospects of IoT medicine [J]. International Journal of Respiration, 2012, 32(18): 1438-1441. DOI: 10.3760/cma.j.issn.1673-436X.2012.018.018.

[2] WAN Zhen, QIU Dan, LIU Yuanzhe, et al. Current status of domestic medical IoT technology development and application [J]. Chinese Medical Equipment Journal, 2020, 41(11): 82-86, 102. DOI: 10.19745/j.1003-8868.2020257.

[3] LI Yanru, ZENG Yongmei, CHENG Li, et al. Visual analysis of IoT application status in chronic diseases [J]. Evidence-Based Nursing, 2021, 7(2): 235-240. DOI: 10.12102/j.issn.2095-8668.2021.02.019.

[4] RAVI P S, MOHD J B, ABID H, et al. Internet of things (IoT) applications to fight against COVID-19 pandemic [J]. Diabetes Metab Syndr, 2020, 14(4): 521-524. DOI: 10.1016/j.dsx.2020.04.041.

[5] HUHN S, AXT M, GUNGA H C, et al. The impact of wearable technologies in health research: scoping review [J]. JMIR Mhealth Uhealth, 2022, 10(1): e34384. DOI: 10.2196/34384.

[6] ROBLYER D M. Perspective on the increasing role of optical wearables and remote patient monitoring in the COVID-19 era and beyond [J]. JBO, 2020, 25(10): 102703. DOI: 10.1117/1.JBO.25.10.102703.

[7] CHANNA A, POPESCU N, SKIBINSKA J, et al. The rise of wearable devices during the COVID-19 pandemic: a systematic review [J]. Sensors, 2021, 21(17): 5787. DOI: 10.3390/s21175787.

[8] World Health Statistics 2017-Monitoring health for the SDGs [EB/OL]. [2021-05-10]. http://www.indiaenvironmentportal.org.in/content/442747/world-health-statistics-2017-monitoring-health-for-the-sdgs/.

[9] WANG C, XU J Y, YANG L, et al. Prevalence and risk factors of chronic obstructive pulmonary disease in China (the China Pulmonary Health [CPH] study): a national cross-sectional study [J]. Lancet, 2018, 391(10131): 1706-1717. DOI: 10.1016/S0140-6736(18)30841-9.

[10] VAN DER HEIJDEN M, LUCAS P J F, LIJNSE B, et al. An autonomous mobile system for the management of COPD [J]. J Biomed Inform, 2013, 46(3): 458-469. DOI: 10.1016/j.jbi.2013.03.003.

[11] CHEN Xiaoping, LI Xing, HE Fei, et al. SWOT analysis of standardized COPD management models based on IoT medicine [J]. China Health Standard Management, 2022, 13(13): 120-124. DOI: 10.3969/j.issn.1674-9316.2022.13.029.

[12] PAN Z H, DICKENS A P, CHI C H, et al. Accuracy and cost-effectiveness of different screening strategies for identifying undiagnosed COPD among primary care patients ($\geq$ 40 years) in China: a cross-sectional screening test accu-

racy study: findings from the Breathe Well group [J]. BMJ Open, 2021, 11(9): e051811. DOI: 10.1136/bmjopen-2021-051811.

[13] LI Fan, GAO Zhen, SHENG Chunfeng, et al. Application effect of mobile internet information platform in COPD graded diagnosis and treatment [J]. Chinese General Practice, 2018, 21(30): 3730-3734. DOI: 10.12114/j.issn.1007-9572.2018.00.030.

[14] TIPPARAJU V V, WANG D, YU J J, et al. Respiration pattern recognition by wearable mask device [J]. Biosens Bioelectron, 2020, 169: 112590. DOI: 10.1016/j.bios.2020.112590.

[15] PIPEK L Z, NASCIMENTO R F V, ACENCIO M M P, et al. Comparison of SpO2 and heart rate values on Apple Watch and conventional commercial oximeters devices in patients with lung disease [J]. Sci Rep, 2021, 11(1): 18901. DOI: 10.1038/s41598-021-98453-3.

[16] HAWTHORNE G, GREENING N, ESLIGER D, et al. Usability of wearable multiparameter technology to continuously monitor free-living vital signs in people living with chronic obstructive pulmonary disease: prospective observational study [J]. JMIR Hum Factors, 2022, 9(1): e30091. DOI: 10.2196/30091.

[17] LIU Yitong, MA Lijun. Research on application and problems of "Internet +" mobile medical technology in stable COPD management [J]. Medical Information, 2019, 32(6): 38-40. DOI: 10.3969/j.issn.1006-1959.2019.06.014.

[18] CUI Jingjing, LIU Yuanyuan, HAO Jingyuan, et al. IoT-based respiratory chronic disease management [J]. Chinese Journal of Geriatric Care, 2021, 19(2): 149-151. DOI: 10.3969/j.issn.1672-2671.2021.02.049.

[19] WU C T, LI G H, HUANG C T, et al. Acute exacerbation of a chronic obstructive pulmonary disease prediction system using wearable device data, machine learning, and deep learning: development and cohort study [J]. JMIR Mhealth Uhealth, 2021, 9(5): e22591. DOI: 10.2196/22591.

[20] FERNANDEZ-GRANERO M A, SANCHEZ-MORILLO D, LEON-JIMENEZ A. Computerised analysis of telemonitored respiratory sounds for predicting acute exacerbations of COPD [J]. Sensors, 2015, 15(10): 26978-26996. DOI: 10.3390/s151026978.

[21] ZHOU Lei, JIANG Yan, DU Chunling, et al. Development and clinical application of IoT portable pulmonary function detectors [J]. International Journal of Respiration, 2019, 39(2): 113-118. DOI: 10.3760/cma.j.issn.1673-436X.2019.02.007.

[22] WANG Guangdong, MA Aiping, CHEN Lingling, et al. Effectiveness analysis of IoT portable spirometry for resident pulmonary function screening in Xiamen [J]. Journal of Clinical Pulmonary Medicine, 2022, 27(11): 1653-1658. DOI: 10.3969/j.issn.1009-6663.2022.11.005.

[23] GURBETA L, BADNJEVIC A, MAKSIMOVIC M, et al. A telehealth

system for automated diagnosis of asthma and chronical obstructive pulmonary disease [J]. J Am Med Inform Assoc, 2018, 25(9): 1213-1217. DOI: 10.1093/jamia/ocy055.

[24] CHUNG H, JEONG C, LUHACH A K, et al. Remote pulmonary function test monitoring in cloud platform via smartphone built-in microphone [J]. Evol Bioinform Online, 2019, 15: 1176934319888904. DOI: 10.1177/1176934319888904.

[25] GAO Lianjun, ZHAO Hongmei. Survey of physicians' cognition and implementation status of pulmonary rehabilitation in medical institutions at all levels in 2017 [J]. Chinese Journal of Tuberculosis and Respiratory Diseases, 2019, 42(4): 275-278. DOI: 10.3760/cma.j.issn.1001-0939.2019.04.006.

[26] VASILOPOULOU M, PAPAIOANNOU A I, KALTSAKAS G, et al. Home-based maintenance tele-rehabilitation reduces the risk for acute exacerbations of COPD, hospitalisations and emergency department visits [J]. Eur Respir J, 2017, 49(5): 1602129. DOI: 10.1183/13993003.02129-2016.

[27] GAGNON S, ROSS B, BOURBEAU J. Video telehealth and pulmonary rehabilitation: need for a better understanding [J]. Am J Respir Crit Care Med, 2020, 201(1): 119-120. DOI: 10.1164/rccm.201907-1394LE.

[28] YANG Lulu, YANG Ting. Research progress of mobile smart devices in respiratory rehabilitation for COPD patients [J]. Chinese Journal of Physical Medicine and Rehabilitation, 2021, 43(8): 748-751. DOI: 10.3760/cma.j.issn.0254-1424.2021.08.019.

[29] FENG Peng, DONG Weiyan, XIE Ting, et al. Application of IoT in respiratory rehabilitation nursing for COPD patients [J]. Chinese Journal of Modern Nursing, 2021, 27(12): 1625-1629. DOI: 10.3760/cma.j.cn115682-20200906-05230.

[30] ZHANG Xin, LI Wenya. Effect of IoT cloud platform-based pulmonary rehabilitation nursing on elderly stable COPD patients [J]. China Medical Science, 2022, 12(15): 127-130. DOI: 10.3969/j.issn.2095-0616.2022.15.032.

[31] XIANG G L, ZHU X D, MA L, et al. Clinical guidelines on the application of Internet of Things (IOT) medical technology in the rehabilitation of chronic obstructive pulmonary disease [J]. J Thorac Dis, 2021, 13(8): 4629-4637. DOI: 10.21037/jtd-21-443.

[32] HONKOOP P, USMANI O, BONINI M. The Current and future role of technology in respiratory care [J]. Pulm Ther, 2022, 8(2): 167-179. DOI: 10.1007/s41030-022-00191-y.

[33] SORINO C, NEGRI S, SPANEVELLO A, et al. Inhalation therapy devices for the treatment of obstructive lung diseases: the history of inhalers towards the ideal inhaler [J]. Eur J Intern Med, 2020, 75: 15-18. DOI: 10.1016/j.ejim.2020.02.023.

[34] HÄUßERMANN S, ARENDSEN L J, PRITCHARD J N. Smart dry powder inhalers and intelligent adherence management [J]. Adv Drug Deliv Rev, 2022, 191: 114580. DOI: 10.1016/j.addr.2022.114580.

[35] ZABCZYK C, BLAKEY J D. The effect of connected smart inhalers on medication adherence [J]. Front Med Technol, 2021, 3: 657321. DOI: 10.3389/fmedt.2021.657321.

[36] JANSEN E M, VAN DE HEI S J, DIERICK B J H, et al. Global burden of medication non-adherence in chronic obstructive pulmonary disease (COPD) and asthma: a narrative review of the clinical and economic case for smart inhalers [J]. J Thorac Dis, 2021, 13(6): 3846-3864. DOI: 10.21037/jtd-20-2360.

[37] BOWLER R, ALLINDER M, JACOBSON S, et al. Real-world use of rescue inhaler sensors, electronic symptom questionnaires and physical activity monitors in COPD [J]. BMJ Open Respir Res, 2019, 6(1): e000350. DOI: 10.1136/bmjresp-2018-000350.

[38] PLEASANTS R A, CHAN A H, MOSNAIM G, et al. Integrating digital inhalers into clinical care of patients with asthma and chronic obstructive pulmonary disease [J]. Respir Med, 2022, 205: 107038. DOI: 10.1016/j.rmed.2022.107038.

[39] JIANG W P, WANG L L, SONG Y L. Titration and follow-up for home noninvasive positive pressure ventilation in chronic obstructive pulmonary disease: the potential role of tele-monitoring and the Internet of Things [J]. Clin Respir J, 2021, 15(7): 705-715. DOI: 10.1111/crj.13352.

[40] LI Maolin, WANG Lili. Design and implementation of health management cloud platform based on home ventilators [J]. Chinese Medical Equipment Journal, 2020, 41(11): 34-39. DOI: 10.19745/j.1003-8868.2020247.

[41] RADOGNA A V, SICILIANO P A, SABINA S, et al. A low-cost breath analyzer module in domiciliary non-invasive mechanical ventilation for remote COPD patient monitoring [J]. Sensors, 2020, 20(3): 653. DOI: 10.3390/s20030653.

[42] GAO Hui, GAO Yuan, SUN Ping, et al. Clinical study of network remote management combined with non-invasive ventilation in treating COPD with respiratory failure [J]. Journal of Clinical Pulmonary Medicine, 2020, 25(3): 347-351. DOI: 10.3969/j.issn.1009-6663.2020.03.006.

[43] LI Wenlong, ZHANG Hua, ZHANG Peng. Effect of IoT cloud platform management on home non-invasive ventilation efficacy and adherence in COPD patients with chronic respiratory failure [J]. Journal of Clinical Internal Medicine, 2017, 34(4): 275-276. DOI: 10.3969/j.issn.1001-9057.2017.04.019.

[44] PINTO A, ALMEIDA J P, PINTO S, et al. Home telemonitoring of non-invasive ventilation decreases healthcare utilisation in a prospective controlled trial of patients with amyotrophic lateral sclerosis [J]. J Neurol Neurosurg Psychiatry, 2010, 81(11): 1238-1242. DOI: 10.1136/jnnp.2010.206680.

[45] TURINO C, DE BATLLE J, WOEHRLE H, et al. Management of continuous positive airway pressure treatment compliance using telemonitoring in obstructive sleep apnoea [J]. Eur Respir J, 2017, 49(2): 1601128. DOI: 10.1183/13993003.01128-2016.

[46] DENNIS H, JEREMIAH W C, ADAM V B, et al. Effect of telemedicine education and telemonitoring on continuous positive airway pressure adherence [J]. Am J Respir Crit Care Med, 2018, 197(1): 117-126. DOI: 10.1164/rccm.201703-0582OC.

[47] PÉPIN J L, JULLIAN-DESAYES I, SAPÈNE M, et al. Multimodal remote monitoring of high cardiovascular risk patients with OSA initiating CPAP: a randomized trial [J]. Chest, 2019, 155(4): 730-739. DOI: 10.1016/j.chest.2018.11.007.

[48] MCLEAN S, NURMATOV U, LIU J L Y, et al. Telehealthcare for chronic obstructive pulmonary disease: Cochrane Review and meta-analysis [J]. Br J Gen Pract, 2012, 62(604): e739-749. DOI: 10.3399/bjgp12X658269.

[49] SORIANO J B, GARCÍA-RÍO F, VÁZQUEZ-ESPINOSA E, et al. A multicentre, randomized controlled trial of telehealth for the management of COPD [J]. Respir Med, 2018, 144: 74-81. DOI: 10.1016/j.rmed.2018.10.008.

[50] BAI Chunxue. Technical platform for changing community and specialist physician service models—the deep-level role of IoT medicine [J]. International Journal of Respiration, 2014, 34(12): 881-882. DOI: 10.3760/cma.j.issn.1673-436X.2014.12.001.

[51] WANG Weigang, WEI Xinping, MA Xuedong, et al. Establishment of COPD patient management model based on IoT in Gumei Community [J]. Fudan University Journal (Medical Science Edition), 2017, 44(3): 344-347. DOI: 10.3969/j.issn.1672-8467.2017.03.015.

[52] CHEN Xiaoping, WENG Chaohang, CHI Haiyan, et al. Research on application of IoT medical technology in pulmonary function screening [J]. Chinese Journal of Health Informatics and Management, 2020, 17(4): 528-532, 543. DOI: 10.3969/j.issn.1672-5166.2020.04.025.

[53] LÜ Mengxuan, QI Zhennan, CHI Chunhua. Impact of wearable device-based smart healthcare on COPD management [J]. Chinese Journal of General Practitioners, 2022, 21(3): 213-218. DOI: 10.3760/cma.j.cn114798-20210918-00711.

[54] JIANG Weipeng, JIN Xin, CHEN Cuicui, et al. Current status and prospects of wearable devices in respiratory diseases [J]. Chinese Journal of Clinical Medicine, 2021, 28(6): 919-924. DOI: 10.12025/j.issn.1008-6358.2021.20210361.

[55] ZHAO Hong, GAO Xiaoli, GUO Beibei, et al. Effect of IoT combined with multidisciplinary diagnosis and treatment rehabilitation nursing model on

COPD rehabilitation outcomes [J]. Journal of Tuberculosis and Lung Diseases, 2022, 3(3): 187-192. DOI: 10.19983/j.issn.2096-8493.20220046.

[56] VAN DER KAMP M R, KLAVER E C, THIO B J, et al. WEARCON: wearable home monitoring in children with asthma reveals a strong association with hospital based assessment of asthma control [J]. BMC Med Inform Decis Mak, 2020, 20(1): 192. DOI: 10.1186/s12911-020-01210-1.

[57] ALWASHMI M F, FITZPATRICK B, FARRELL J, et al. Perceptions of patients regarding mobile health interventions for the management of chronic obstructive pulmonary disease: mixed methods study [J]. JMIR Mhealth Uhealth, 2020, 8(7): e17409. DOI: 10.2196/17409.

[58] BENTLEY C L, POWELL L, POTTER S, et al. The use of a smartphone app and an activity tracker to promote physical activity in the management of chronic obstructive pulmonary disease: randomized controlled feasibility study [J]. JMIR Mhealth Uhealth, 2020, 8(6): e16203. DOI: 10.2196/16203.

[59] TANG Ling, GUO Aimin, YU Jie, et al. Qualitative study on community elderly COPD patients' needs for mobile health-based health education [J]. Chinese Nursing Management, 2022, 22(4): 537-542. DOI: 10.3969/j.issn.1672-1756.2022.04.012.

[60] KHUNDAQJI H, HING W, FURNESS J, et al. Wearable technology to inform the prediction and diagnosis of cardiorespiratory events: a scoping review [J]. PeerJ, 2021, 9: e12598. DOI: 10.7717/peerj.12598.

[61] CAULFIELD B, KALJO I, DONNELLY S. Use of a consumer market activity monitoring and feedback device improves exercise capacity and activity levels in COPD [J]. Annu Int Conf IEEE Eng Med Biol Soc, 2014, 2014: 1765-1768. DOI: 10.1109/EMBC.2014.6943950.

[62] YAMAMOTO A, NAKAMOTO H, YAMAGUCHI T, et al. Validity of a novel respiratory rate monitor comprising stretchable strain sensors during a 6-Min walking test in patients with chronic pulmonary obstructive disease [J]. Respir Med, 2021, 190: 106675. DOI: 10.1016/j.rmed.2021.106675.

[63] KAYYALI R, SAVICKAS V, SPRUIT M A, et al. Qualitative investigation into a wearable system for chronic obstructive pulmonary disease: the stakeholders' perspective [J]. BMJ Open, 2016, 6(8): e011657. DOI: 10.1136/bmjopen-2016-011657.

(Received: June 11, 2023; Revised: August 11, 2023)
(Editor: CUI Sha)

Note: Figure translations are in progress. See original paper for figures.