MOBILE HEALTH APPLICATIONS FOR COPD SELF-MANAGEMENT

THE STATE OF CHRONIC OBSTRUCTIVE PULMONARY DISEASE (COPD) APPS: IDENTIFYING IDEAL DESIGNS AND FEATURES TO SUPPORT PATIENTS' SELF-MANAGEMENT

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TITLE: The State of COPD Apps: Identifying Ideal Designs and Features to Support Patients' Self-Management

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LAY ABSTRACT

There are different treatments to help patients control their chronic obstructive pulmonary disease (COPD), but many Canadians with COPD continue to feel physically, mentally, and socially limited. This shows the need for better resources to support people living with COPD, helping them understand and manage their disease better. Mobile health applications (mHealth apps) may be a possible solution as they are popular and easy to access. Unfortunately, current information is not strong enough to make conclusions on whether apps can be used to support COPD self-management plans. The main objective of this thesis was to identify the best way to grade the characteristics, features and qualities of COPD apps in past research studies and in the public marketplace. The secondary objective was to seek feedback on whether public COPD apps are good enough to consider in care plans, from the perspective of healthcare providers and people living with COPD.

ABSTRACT

Introduction: Mobile health applications (mHealth apps) may support people's chronic obstructive pulmonary disease (COPD) self-management. Current research has demonstrated the promising effects of mHealth apps for people with COPD but there is still limited information on these apps' characteristics and qualities, especially those in the public domain. Therefore, there is the need to use a standardized evaluation framework to: 1) describe characteristics and qualities of COPD apps from past studies; 2) characterize the features and qualities of public COPD apps; and 3) determine the appropriateness of public COPD apps from the perspective of clinicians and patients living with COPD.

Methods: The mHealth Index and Navigation Database (MIND) framework, an objective evaluation tool was applied across studies.

Project 1: A systematic review was conducted, including randomized controlled trials investigating interactive mHealth apps for people living with chronic lung diseases (CLD).

Project 2: An evaluation study of the public marketplace (Android and Apple app stores) was conducted. Free mHealth apps created specifically for COPD self-management were included.

***Project 3*:** Reviewed COPD apps were presented to stakeholders in an infographic format. A RAND/UCLA Appropriateness Method (RAM) was used to collect feedback from stakeholders on the state of public COPD apps.

Results: Many of the COPD apps trialed in past studies have inconsistent reports of their features and qualities, with many publicly unavailable. Most public COPD apps lacked clinical evidence to support their use and have questionable qualities. Stakeholders agreed that public COPD apps were mostly inappropriate but did not dismiss the need to discuss their potential in COPD care plans.

Significance: This thesis project advocates for the partnership with multiple heath disciplines and patient-participants for app evaluations to gain stronger understanding of their potential. Future opportunities may include exploring other apps for lung diseases to promote stakeholder engagement throughout the process.

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My interest in respiratory health led me to become a respiratory therapist. Although the job was demanding, exhausting yet rewarding, I felt like I was still missing something: research. When I entered the respiratory therapy profession, I promised myself that I would find a way to do research again, one day. But I quickly learned how difficult that was as a respiratory therapist… until I met Dr. Mika Nonoyama. Mika, you showed me that there will always be a solution, even if there is a barrier. None of this would have been possible without you – you were

my mentor in this space, and I am truly grateful to be your colleague and a member of our small Lung Health Initiative Group at the Hospital for Sick Children. You are always looking out for me, and always giving me opportunities to self-reflect, develop, and improve as a leader, mentor, and clinical researcher.

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LIST OF ABBREVIATIONS

ABACUS	App Behaviour Change Scale
APA	American Psychiatric Association
Apps	Applications
CAD	Canadian dollar
CADTH	Canadian Agency for Drugs and Technology in Health
CIHR	Canadian Institute of Health Research
CINAHL	Cumulative Index to Nursing and Allied Health Literature database
CLD	Chronic lung disease
COPD	Chronic obstructive pulmonary disease
COVID-19	Corona-virus disease 2019
CTS	Canadian Thoracic Society
DHI	Digital health intervention
EBP	Evidence based practice
EMR	Electronic medical records
EQUATOR	Enhancing the Quality and Transparency Of health Research
FDA	Food Drug Administration
FEV1	Forced expiratory volume within 1 second
FKGL	Flesch-Kincaid grade level
FVC	Forced vital capacity
GOLD	Global Initiative for Chronic Obstructive Lung Disease
HIPAA	Health Insurance Portability and Accountability Act
HONS code	Health on the Net Code

KT	Knowledge translation
KTA	Knowledge to Action (cycle)
MARS	Mobile App Rating scale
mERA	Mobile health (mHealth) evidence reporting and assessment
MHAD	Mobile Health App Database
mHealth	Mobile health
MIND	mHealth Index and Navigation Database
mMRC	Modified Medical Research Council
N, n	Sample size
NHS: Wales	National Health Service for Wales
PHI	Personal health information
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
Q1	1st quartile
Q3	3rd quartile
RAM	RAND/UCLA Method
RAND/UCLA	Rand Corporation/ University of California of Los Angeles
RCT	Randomized controlled trials
REB	Research ethics board
REDCap	Research Electronic Database Capture
SD	Standard deviation
TEACH-apps	Technology Evaluation and Assessment Criteria for Health apps
WHO	World Health Organization

LIST OF SYMBOLS

%	Percent
$	Dollar
/	Out of
=	Equals
<	Less than
>	Greater than
≤	Less than or equal to
≥	Greater than or equal to
±	Plus or minus

DECLARATION OF ACADEMIC ACHIEVEMENT

The manuscripts of the scholarly work in this thesis are presented in Chapters 2 to 4. The subheadings and formatting of each manuscript were structured as required by the journals to which they were submitted. I, Shirley Quach, contributed significantly to each project and their subsequent manuscript; therefore, I am the primary (first) author for each manuscript.

PHD CANDIDATE CONTRIBUTIONS

Chapter 2: Mobile health applications for self-management in chronic lung disease: a systematic review

I developed the research question, methods and performed the preliminary search. I performed the search across the different databases, screened and reviewed articles. I extracted, interpreted, and summarized the data. I drafted the initial manuscript, reviewed, revised, and finalized the manuscript for publication.

Chapter 3: Features and characteristics of publicly available mHealth apps for self-management in chronic obstructive pulmonary disease

I designed the study and performed the literature review, app search, app assessment, data extraction, analyses, interpretation, summarization and final presentations. I drafted the initial manuscript, reviewed, revised, and finalized the manuscript for publication.

Chapter 4: Public Mobile Chronic Obstructive Pulmonary Disease Applications for self-management: Patients and Healthcare Professionals' Perspectives

I conceptualized the study, applied for ethics approval from the Hamilton integrated Research Ethics Board and managed the yearly renewals. I developed all the study documents, including the patient consent forms, recruitment poster, invitations, focus group guide and survey template. I was primarily responsible for participant recruitment, follow-up, data collection, data analyses

including coding of the focus group meetings. I drafted the initial manuscript, reviewed, revised and finalized the manuscript for publication.

CO-AUTHORS' CONTRIBUTIONS:

Chapter 2: Mobile health applications for self-management in chronic lung disease: a systematic review

Wade Michaelchuk assisted in the literature search, conceptualization, data extraction, analyses and provided feedback for the final manuscript. Adam Benoit assisted in data extraction, analyses and finalized the manuscript. Ana Oliveira, Tara L. Packam, Roger Goldstein and Dina Brooks assisted in the conceptualization, interpretations and provided feedback for the manuscript draft. All co-authors provided feedback and approved the final manuscript.

Chapter 3: Features and characteristics of publicly available mHealth apps for self-management in chronic obstructive pulmonary disease

Adam Benoit assisted in data collection and analyses. Ana Oliveira, Tara L. Packham, Roger Goldstein, and Dina Brooks assisted in study conceptualization, interpretation and provided feedback for the manuscript draft. All co-authors provided feedback and approved the final manuscript.

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Adam Benoit assisted in the data collection and analyses. Tara L. Packham, Roger Goldstein and Dina Brooks assisted in study conceptualization, interpretation and provided feedback for the manuscript draft. All co-authors approved the final manuscript.

CHAPTER 1: INTRODUCTION:

1.1 CHRONIC OBSTRUCTIVE PULMONARY DISEASE (COPD)

The global prevalence of COPD has steadily increased since 2004, with over 200 million reported cases globally in 2019.[1,2] COPD is one of the top five leading cause of death, accounting for approximately 3.23 million worldwide deaths in 2019.[3,4] The World Health Organization (WHO) predicts Chronic obstructive pulmonary disease (COPD) will be one of the top three leading causes of death by 2030, likely accounting for 8.6% of worldwide deaths.[4] In 2020, approximately 800,000 Canadians, over 10% of the population were diagnosed with COPD, and approximately 770,000 of these individuals were aged 50 and older.[5] People living with COPD are burdened by many debilitating pulmonary and systemic symptoms, affecting their overall health,[6-9] increasing personal and societal financial burden.[1,4,6] It is estimated that the average cost to treat patients with COPD ranges from $3910 to $6693 CAD per person, with disease severity positively correlating with costs.[7] Therefore, COPD continues to be a public health concern, emphasizing the need to strategically minimize the factors for COPD and to optimize treatments to alleviate the impacts of COPD.[2,7,10]

The Global Initiative for Chronic Obstructive Lung Disease (GOLD) defines COPD as a heterogenous lung disease, characterized by two lung conditions: chronic bronchitis and emphysema, caused by abnormalities in the airways and/or alveolar tissues, respectively.[11] Individuals with COPD can have one or the other lung abnormality, with many having both.[12] Pathophysiologic changes observed in COPD are likely due to the cumulative effects of ageing, genetic factors and prolonged chemical exposures, leading to declining and impaired lung function.[3,11,13,14] Pathophysiologic changes leads to increased airflow resistance in the airways, and increased lung compliance, both attributing to obstruction and air trapping.[15] However, there

is substantial variation in disease progression across populations and age groups, preventing generalization of COPD risk factors and trajectories.[10,16,17] Although there are no cures for COPD, current strategies prioritize minimizing COPD risk factors at the population level, including smoking cessation and reducing environmental exposures to pollutants.[6,11,12] Once diagnosed, there are effective treatments to alleviate symptoms, decrease disease burden and improve quality of life.[11,15]

1.1.1 PATHOPHYSIOLOGY

Consistent exposure to tobacco smoke, occupational and environmental air pollutants are identified as major risk factors for many chronic respiratory diseases, including in COPD development.[10,12,15,18] These inhalational irritants amplify the respiratory system's protective mechanisms, triggering hyperinflammatory responses, leading to airway, lung parenchyma and vasculature changes and destruction.[12,13,15] In addition, excessive inflammation leads to persistent oxidative stress, which normal defence mechanisms are unable to mediate, further exacerbating this cycle of hyperinflammation and destructive lung changes.[13,18] These predisposing factors are strong facilitators in declining lung health, and further intensify the deterioration in lung function seen in ageing.[17] COPD severity is dependent on how imbalanced the inflammation and repair mechanisms are, with increased COPD severity attributed to greater imbalance.[13]

Inevitably, physiological abnormalities will develop depending on whether the hyperinflammation process affects and damages the conducting airways or the lung tissues and parenchyma, or both.[13,14] These abnormalities can be distinctly classified as the two lung conditions presented in COPD, chronic bronchitis and emphysema.[18] In chronic bronchitis, pathophysiological consequences lead to mucus hypersecretion in the airways, coupled with underlying ciliary dysfunction and poor cough flows.[13] The excessive mucus and lack of

clearance leads to increased risks of airflow obstruction and frequent infections.[11,12] In contrast, destruction of the elastic fibers in lung tissues lead to overly compliant lung tissues, increasing the risk for hyperinflation, expiratory flow limitation and gas exchange abnormalities, seen in emphysema.[18] Both pathogenic changes and conditions may be present, but it is possible for people with COPD to have one or the other.[11] Regardless, these pathophysiological responses are non-reversible and result in cardiopulmonary damages that manifest as respiratory and non-respiratory symptoms.[12,18]

1.1.2 CLINICAL PRESENTATION AND DISEASE BURDEN

The symptoms experienced by people with COPD depend on the lung conditions present, with symptom severity varying daily and seasonally.[11,16] Several respiratory symptoms observed in people with COPD are shortness of breath, chronic coughs, wheezing, chest tightness and frequent respiratory tract infections.[2,11,19] Dyspnea, in combination with other respiratory symptoms is debilitating, and is associated with other systemic consequences,[13] affecting many aspects of people's lives.[16,20]

If not managed effectively, dyspnea prevents patients from performing their usual daily activities of living,[2,6,7] with some patients requiring assistance from others.[16] This leads to people constantly worrying about their dyspnea, leading them to reduce their physical activity levels to prevent worsening breathlessness and needing assistance.[16,19] This fear of worsening dyspnea feeds into their anxiety, perpetuating their feelings of breathlessness and panic attacks in an endless debilitating cycle.[19-21] For these reasons, many people with COPD avoid any form of physical activity, adopt sedentary lifestyles and socially isolate themselves.[16,22] Accepting these limitations as consequences of their disease lead people with COPD to live with an overall poor quality of life, negatively impacting their physical, social and psychological well-being.[7,20-22]

1.1.3 COMORBIDITIES IN COPD

COPD is primarily a disease that affects the lungs and the respiratory system. However, many people who live with COPD frequently have other underlying non-respiratory comorbidities.[16,23,24] Heart disease, hyperlipidemia, osteoporosis, musculoskeletal disorders, anxiety and depression are some of the most common documented comorbidities.[11,23,25] In fact, the chronic respiratory and systemic inflammation observed in COPD is believed to be only one component of a systemic multi-component disease.[23,25,26] Regardless of which disease coexists with an individual's COPD, the combined effects of these comorbidities are detrimental to their quality of life.[16,26,27] Therefore, it is imperative for people living with COPD and comorbidities to have treatment options that will address their various symptoms and needs, to minimize poor health outcomes and reduce their mortality risk.[20,23-25,27]

1.1.4 COPD DIAGNOSIS AND TREATMENT

If COPD is suspected, a diagnosis can only be confirmed after measuring lung function using forced spirometry repeatedly.[10,17] Airflow obstruction and severity are measured using a ratio between forced expiratory volume within 1 second (FEV1) and forced vital capacity (FVC).[11] As per the GOLD guideline,[11] FEV1/FVC ratios less than 70% after bronchodilators indicate airflow limitation, and increased likelihood of COPD. COPD severity is classified based on the degree of airflow limitation, with greater airflow obstruction (lower FEV1/FVC %) correlating with disease severity.[11,12]

There are interventions and therapies available to manage dyspnea and the associated health consequences in COPD.[11,17] The GOLD Pocket guide and the recent Canadian Thoracic Society (CTS) COPD guideline emphasized the importance of proper COPD diagnosis, frequent follow ups, and evidence-informed treatments in effective COPD management.[17,28] The primary

goals of COPD management are to improve people's symptoms, exercise tolerance and overall health status to reduce acute exacerbations, morbidity and mortality.[11] One key aspect is the prevention of acute exacerbations, defined as acute episodes of lung function deterioration, usually triggered by infections, that lead to increased risks for hospitalizations, poorer health outcomes and mortality.[18,28] Proper COPD management is multicomponent and comprehensive, including pharmacological and non-pharmacological interventions that should be tailored to meet patients' personal needs to maintain COPD stability.[11,15]

Pharmacological therapy is available to help alleviate symptom burden, reduce exacerbation frequency, mortality and improve quality of life.[11,18] However, pharmacological therapy should be carefully tailored and adjusted to each individual, and the composition should be dependent on the COPD severity.[28,29] At minimum, patients should be prescribed with daily inhaled medications to reduce their shortness of breath and to maintain overall good health.[17] There are different combinations of bronchodilators and corticosteroids available, and if symptoms are still not well controlled, additional types of pharmacological agents may be included, e.g., methylxanthines.[29]

A comprehensive COPD management plan should also include non-pharmacological therapies, considering components of smoking cessation, pulmonary rehabilitation, education on their disease and self-management principles, psychosocial support, and exercise training.[11,17,30] These lifestyle changes are meant to promote healthier choices in patients' lives and encourage patients to gain the autonomy, confidence and skills to self-regulate and manage their disease.[30-32] Dependent on the COPD severity and patients' disease progression, additional medical therapies such as oxygen therapy or non-invasive ventilation can be considered, with surgical

and endoscopic interventions available to those who continue to experience poor COPD management after exhausting pharmacological and non-pharmacological options.[11]

1.1.5 SELF-MANAGEMENT IN COPD

Self-management is one of the most important components of non-pharmacological interventions in treating COPD.[32] COPD self-management is personalized, designed to encourage patients to take ownership of their own health by equipping them with knowledge and skills to effectively cope with COPD and its symptoms.[11,31,33] Self-management can be described as a structured and personalized multicomponent intervention, co-designed by the patient, family and healthcare team to motivate, and support patients to adopt positive, healthy behaviours and skills to better control their disease.[30,33] When personalized, self-management is effective in improving patient outcomes in their physical, social, and psychological health.[34] Although the consensus definition of self-management has been established,[33] there is no strong recommendation on the absolute composition of self-management plans as they can include education, self-monitoring, symptoms management, physical activity, dietary modifications and smoking cessation.[20,34] The personalized and tailored nature of self-management plans make them difficult to evaluate.[34,35] Since self-management plans are meant to be patient-centered, they are heterogenous in design, measured outcomes and implementation, adding to the complexity of understanding which is the best composition to maximize patient support.[36]

Likely due to the variability and lack of standardized self-management plans, patients continue to express unmet needs in COPD self-management.[20,22,33,35] In a qualitative study by Sigurgeirsdottir,[20] participants with COPD expressed an urgent need for learning how to manage and cope with their non-curable disease, and for psychosocial and social support. Similarly, in a COPD needs assessment study by Wortz et al,[35] patients with COPD expressed strong desires for

improved care, possibly through the process of learning and improved health literacy. Developing a self-management plan must be iterative, including feedback from both patients and healthcare team members to ensure identified needs are addressed and barriers are mitigated.[33,35] Self-management plans must be frequently reviewed and revised, as it should equip patients with knowledge and skills through all stages of their COPD disease.[36]

1.2 MOBILE TECHNOLOGY

Digital health and technology have gained popularity over the last few decades, and are increasingly being integrated into the healthcare sector.[37] Ideally, digital transformation of health services and resources optimize system costs by facilitating efficient healthcare delivery,[38] interprofessional communication[39] and accessible care.[37,40] WHO recently updated their publication on the taxonomy and categorization of the term: *digital health*.[38] In this 2023 publication, WHO revised their digital health classification framework to include three main sections: 1) health system challenges; 2) digital health interventions (DHI); and 3) digital services and application types. However, these three sections are not exclusive of each other, as DHI should be considered in tackling current health system challenges by identifying the best digital services and infrastructure to execute the desired the outcomes.[38]

The term DHI can be used to describe a variety of tools and adjuncts that are available to provide people with information quickly and conveniently.[38,39] WHO defines DHI as any electronic, digital or mobile technology that can facilitate and support healthcare delivery, further categorized based on how the DHI addresses personal and system needs.[38] DHI includes multiple modalities and tools to support communication and information sharing, such as internet of things, wearables, monitoring sensors, telemedicine (telehealth), mobile health (mHealth), artificial intelligence and information systems.[40,41] WHO categorizes DHI based on how they are

used to address care and their intended target users, either: 1) clients or patients; 2) clinicians; 3) health system; or 4) data services. As digital technology will continue to evolve and be heavily integrated into the healthcare sector, there is an emphasis on the need for understanding the role and potential of DHI.[38,39,42]

DHI has been commonly used in the literature to describe the digitization of public health information and care, and synonymously used with e-health or mobile health (mHealth).[40,43] Although mHealth falls within this broad definition of DHI, mHealth specifically pertains to disease prevention, monitoring, or treatment, using wireless and mobile technologies, namely smartphones to facilitate rapid data sharing and communication.[43,44]

1.2.1 MOBILE HEALTH APPLICATIONS (MHEALTH APPS)

In 2018, Statistics Canada reported 88% of the Canadian population owned a smartphone and ownership continues to rise across all age groups.[45,46] Smartphones have evolved dramatically, facilitating day-to-day living and patient care across all levels.[41,47] Smartphones have the capability to utilize specialized software, called applications (apps).[37,40,48] Apps are specialized software, information and communication technology systems or channels, designed to deliver digital health content.[38] Within mHealth apps, different features may be available for different purposes and may serve as data collection software for adjunct devices, e.g., wearables, biosensors.[47] Since mHealth apps are widely available and may have a role in disease self-management, they are frequently explored in clinical trials.[44,49]

1.2.2 MHEALTH APPS IN CHRONIC DISEASES

The idea of using mHealth apps to support chronic disease management became more popular since the COVID-19 pandemic. Depending on their available features, mHealth apps can support people looking for additional resources to help understand and manage their disease.

Systematic reviews evaluating the effectiveness of mHealth apps in treatment adherence showed significant clinical improvements in different populations, including cardiovascular, lung, psychiatric and diabetes.[50,51] These favourable results may be due to a combination of features such as reminders, tracking, interactive feedback and clinical decision support, shown across studies.[51,52] However, caution should still be applied to these findings as many reviews report the low grade evidence of included studies.[50,52]

1.3 MHEALTH APPS AND COPD SELF-MANAGEMENT

1.3.1 EVIDENCE ON USE OF COPD APPS

mHealth apps and mobile technology may be helpful interventions in supporting COPD self-management; however, there is limited evidence to draw conclusive recommendations on their use.[49,53] Contradictory information has been presented in several systematic reviews, showing that the use of mHealth apps may not significantly improve patient's self-management behaviour,[54] physical function or [55] quality of life.[50,55,56] However, mHealth apps may have the potential to decrease hospitalizations and hospitalization time,[56] even though pooled data was not possible due to inconsistent features across interventional apps. In short, there is insufficient clinical data to make recommendations on whether digital interventions, including mHealth apps, are effective compared to traditional COPD self-management interventions.[49,53] This demonstrates that current, available COPD apps vary in features, contents and evidence, resulting in various measured outcomes.[55] These variabilities make it difficult for patients and healthcare providers to identify acceptable apps that can be effectively integrated into their care.[57]

The insufficient data may be due to the inconsistency in reporting the design and qualities of mHealth apps in clinical trials.[43,53] As many research teams create their own mHealth apps for

their clinical trials, their design and qualities are inherently unidentical, and are measured or implemented differently.[58,59] Furthermore, in a scoping review by Grainger et al.,[60] the authors noted the lack of application of reporting guidelines or evaluation tools for mHealth apps.

1.3.2 PUBLIC COPD APPS

There are many mHealth apps that are free and easily accessible to the public, making them attractive for people seeking additional information about their disease. However, there is limited research focusing on the qualities and features of commercial, public mHealth apps.[61-65] In the context of COPD, many COPD apps assessed and reported in clinical trials are usually not re-evaluated in larger trials and remain unavailable to the public. This eliminates the possibility of accessible well-designed and high-quality COPD apps in the public space. Instead, many public mHealth apps advertised for COPD and other chronic lung disease self-management are created by for-profit organizations, equipped with variable features and unknown effectiveness.[64-67] This observation is unsurprising and aligns with recent publications reporting on the lack of quality in public mHealth apps in other disease populations.[61,68,69]

1.4 APP FEATURES

Qualities and features of mHealth apps vary across studies, and in the marketplace. App features can be classified as passive or interactive.[70] Passive features include education, data summary, reminders, or tracking. While active features provide users with feedback based on the input the app receives, such as action plans, two-way communication, or clinical decision support tool. Most apps reported in the literature have a combination of passive and interactive features,[49,51,53,70] while public mHealth apps have mostly passive.[64,66,67] However, there is no clear understanding on which combination of features would likely elicit behavioural changes leading to positive health outcomes.[71]

1.5 STANDARDS IN APP REPORTING AND ASSESSMENTS

The United States' Food and Drugs Administration (FDA) and Health Canada do not classify mHealth apps as medical devices and acknowledge the difficulty in regulating their development and use.[48,72,73] However, the lack of regulation can lead to poorly designed, revised and updated mHealth apps that may carry the risk of misinformation, compromising patient and public health safety.[73,74] Since there are hundreds and thousands of mHealth apps available in both the Android and Apple marketplace, it is a challenging task to monitor their quality.[69,72]

Before using any mHealth apps, they must be carefully evaluated for their quality and features, especially those available in the public marketplace. Specifically, evaluations should consider seven main assessment criteria: 1) design; 2) information/ content; 3) usability; 4) functionality; 5) ethical issues; 6) security and privacy; and 7) user-perceived value.[75] There are numerous evaluation frameworks and models to support clinicians in making informed decisions on which mHealth apps can be recommended to patients seeking support from mHealth apps.[72] Unfortunately, there is no current consensus or guideline to inform clinicians and patients on how to select high quality apps,[58,60] leading to inconsistent use of available evaluation tools across studies.[69,75,76] Ideally, evaluation tools should be straightforward, thorough and applicable across different health domains.[77] However, several limitations to current evaluation tools are their lack of assessing security and privacy elements, and whether mHealth apps were in alignment with current clinical evidence and guidelines.[76] Despite these shortcomings, the importance of using existing mHealth app evaluation tools and checklists is repeatedly advocated in the literature.[43,60,75,76]

To improve reporting consistency, the WHO mHealth Technical Evidence Review Group developed the mHealth Evidence Reporting and Assessment (mERA) checklist.[43] Endorsed by

the Equator Network, the mERA checklist identifies the fundamental information and qualities that should be reported and present in all interventional studies. However, the mERA checklist is not frequently used, especially on mHealth apps designed for COPD self-management.[78,79]

The Canadian Agency for Drugs and Technologies in Health (CADTH) identified at least ten app evaluation tools and guides, created by Canadian and international workgroups.[72] Many of the cited evaluation guides are for any or mental health apps, with two guides originating from the Canadian Medical Association[80] and the Mental Health Commission of Canada.[81] Within that list, the Mobile App Rating Scale (MARS),[65,77,82] the American Psychiatric Association's (APA) App Advisor[57,83] and the mHealth Index and Navigation Database (MIND)[63,68] are well-documented in the literature. The MARS is a generic mHealth app assessment tool with good reliability, designed to be used by any clinicians, researchers, and end-users to identify high quality apps.[77] The MARS tool covers domains related to: 1) engagement; 2) functionality; 3) aesthetics; 4) information; and 5) subjective quality. Although the MARS addressed many domains, one of the limitations is the lack of clarity regarding what MARS scores correlated with acceptable apps.[76] The basis of the MARS tool was implemented into the Mobile Health App Database (MHAD), a repository offering clinicians and users information of MARS rated apps.[84] Another tool, the APA App Advisor, was created to inform psychiatrics and mental health professionals on the important elements to consider when choosing apps to recommend to patients.[85] Created by an interdisciplinary team, this evaluation model covers a broad range of domains: 1) background information; 2) risk-privacy and security; 3) evidence; 4) ease of use; and 5) interoperability. As of 2021, the APA App Advisor model was updated to be an objective evaluation tool, and also known as the MIND Framework.[63]

1.6 MIND FRAMEWORK

The APA App Advisor evaluation tool was expanded to include 105 objective questions, informed by 45 app evaluation models, covering six different domains: 1) Accessibility; 2) Privacy and Security; 3) Inputs and outputs; 4) Engagement style; 5) Clinical Foundation; and 6) Interoperability (data sharing and therapeutic goals). The 105 objective questions are operationalized to be binary or numeric, allowing for clearer information sharing.[63] The MIND framework has good interrater reliability (Kappa ≥70%), reported in past studies evaluating mental health apps.[63,86,87] Another strength is the inclusion of questions focused on apps' accessibility, specifically considerations for diversity, equity and inclusivity, making the MIND Framework one of the very few to address these points.[88] Furthermore, the questions in the MIND framework are consistently reviewed and updated to ensure ongoing relevance as mHealth marketplace grows, shown on their website (https://mindapps.org/) and emerging research.[68,86,87,89]

Although the MIND Framework was created for mental health apps, it is still relevant to apps for other conditions, especially questions surrounding privacy, security, clinical evidence, and data sharing. Furthermore, disease-specific criteria may be easily incorporated to address priorities from other subspecialities, demonstrating its flexibility compared to past tools.[63]

1.6.1 AN EXAMPLE WITH MIND REPOSITORY FOR MENTAL MHEALTH APPS

In addition to operationalizing the questions within the MIND framework, there is a centralized electronic repository to house MIND evaluations of public mental mHealth apps (https://mindapps.org/). The idea of the MIND database is to continuously collect objective evaluations of apps as they continue to grow and update. To date, the database is supported by trained volunteers, consistently reviewing apps to crowdsource the evaluations. This database

can be navigated and filtered to identify apps that meet the preferences of users and clinicians, ensuring they are well informed of finding the most clinically relevant apps for their needs.[63] This is the first, interactive comprehensive app evaluation framework in the mental health domain, allowing for transparent knowledge sharing and discussions amongst interested users.

1.7 KNOWLEDGE TO DATE AND PROBLEM

About 45% of Canadians living with COPD continue to experience poor health with limitations to their daily activities,[8] negatively impacting their physical, mental and social lives.[20,90] Understanding how to mitigate these challenges is crucial, as current strategies should consider patients' wishes for better resources to understand and cope with their disease.[91] These identified needs encompass elements related to controlling symptoms, understanding the progression of COPD, seeking relevant resources, psychologically coping with the disease,[91] identifying financial needs, and refining relationships.[90,91] mHealth apps have been reported to be feasible for remote self-management plans.[55,56] Generally, patients have positively accepted mHealth apps as feasible and supportive tools to address some of their needs, emphasizing their potential in COPD self-management.[56] Nonetheless, there are patient-related barriers to consider in apps use, such as age, where increased age correlated with decreased app use,[92,93] a highly anticipated problem for people with COPD as COPD prevalence increases with age. However, past studies have revealed privacy and security concerns, lack of digital literacy, poor app usability and implementation are the strongest barriers to mHealth adoption in patients.[92-96] Therefore, it is important to consider features and qualities that are desirable to patients and address facilitators and barriers that can empower patient-users to learn and improve their self-management.[20,93,96]

There is minimal regulation behind public mHealth apps and there needs to be greater

effort in evaluating their qualities to optimize their use in clinical practice.[63,72] The exponential growth and dynamic changes of mHealth apps has created challenges in their effective adoption.[37,78] Unlike public mental health apps, there is no online repository to provide clinicians and potential users on the qualities and features of public COPD apps. These public COPD apps may have potential to fulfill patients' support needs, but they must be comprehensively evaluated using evidence-based frameworks.[62] Thus, future research needs to utilize existing frameworks and tools to assess public mHealth apps, working towards standardizing the evaluation process for mHealth apps across all health domains.[43,57,63,75,76,79]

1.8 THESIS OBJECTIVES

The overall objective is to evaluate the current state of public COPD mHealth apps using a comprehensive app evaluation framework.

The secondary objectives are to:

1) Evaluate the characteristics and qualities of mHealth apps for chronic lung diseases reported in the literature;
2) Identify whether public COPD apps are appropriate for self-management from the perspectives of patients with COPD and healthcare professionals.

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CHAPTER 2: A SYSTEMATIC REVIEW IN MHEALTH APPS FOR CHRONIC LUNG DISEASES

Mobile health applications for self-management in chronic lung disease: a systematic review

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Mobile health applications for self-management in chronic lung disease: a systematic review

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2.1 ABSTRACT

Introduction: Integration of mobile health applications (mHealth Apps) into chronic lung disease management is becoming increasingly popular. MHealth Apps may support adoption of self-management behaviours to assist people in symptoms control and quality of life enhancement. However, mHealth Apps' designs, features, and content are inconsistently reported, making it difficult to determine which were the effective components. Therefore, this review aims to summarize the characteristics and features of published mHealth apps for chronic lung diseases.

Method: A structured search strategy across five databases (CINAHL, Medline, Embase, Scopus and Cochrane) was performed. Randomized controlled trials investigating interactive mHealth Apps in adults with chronic lung disease were included. Screening and full-text reviews were completed by three reviewers using Research Screener and Covidence. Data extraction followed the mHealth Index and Navigation Database (MIND) Evaluation Framework (https://mindapps.org/), a tool to help clinicians determine the best healthcare apps to address patients' needs.

Results: Over 90,000 articles were screened, with 16 papers included. Fifteen distinct apps were identified, eight for chronic obstructive pulmonary disease (53%) and seven for asthma (46%) self-management. Different resources informed app design approaches, accompanied with varying qualities and features across studies. Common reported features included symptom tracking, medication reminders, education, and clinical support. There was insufficient information to answer MIND questions regarding security and privacy, and only five apps had additional publications to support their clinical foundation.

Conclusion: Current studies reported designs and features of self-management apps differently. App design variations create challenges in determining effectiveness and suitability for chronic lung disease self-management.

Registration: PROSPERO (CRD42021260205)

2.2 INTRODUCTION

The increased prevalence and burden of chronic lung disease on patients requires greater attention towards cost-effective tools to facilitate and support patient-care [1-3]. Over the last few years, chronic disease management programs have incorporated elements of telehealth to maximize access to healthcare services and reduce costs [4]. Telehealth is defined as a tool to facilitate virtual care, which may include mobile health applications (mHealth Apps), web-based tools, telecommunication services, wearable devices and social media [5,6]. MHealth Apps have features to help users understand and manage their disease by providing monitoring and feedback, education, medication reminders and rehabilitation support [4,5]. Recent studies have explored the effectiveness and feasibility of incorporating mHealth apps into people's self-care by modifying their behaviours [7-9]. With the COVID-19 pandemic, interest in using mHealth apps increased significantly, as their use were viewed as simple and accessible tools to safely promote virtual health [10].

People living with chronic lung diseases present with several chronic pulmonary and extrapulmonary symptoms that limit their daily activities and mental well-being [11], impacting their quality of life [2,12]. Managing these consequences and delaying its progression is imperative. Effective disease management requires changes to patients' behaviours [7], encompassing elements of education, symptom control, and physical activity [12-14]. Practice guidelines advocate for patient-centered approaches between patients and healthcare teams to adopt effective self-management behaviours, but their implementation is often poor [8,15,16]. Lack of appropriate implementation may be due to patients' complex social and emotional needs, and the limited time and resources healthcare providers have [13,15]. Alternatively, mHealth Apps are widely available, and may help overcome these barriers [3,12,14,16,17], by empowering patients to adhere to their self-care regime over long periods of time [1,8,18]. Patients have expressed interest in using

mHealth interventions to learn and develop skills to manage their disease [6,16,19,20]. Reported benefits of mHealth Apps, included decreased hospitalization, improved symptom control and quality of life [15,21]. However, systematic reviews reported no significant improvements in patients' outcomes, possibly due to the heterogeneity of mHealth apps [22]. Reported designs and contents of mHealth Apps in previous studies are inconsistent [23]. Therefore, an assessment of mHealth Apps for chronic lung disease is required to characterize their reported designs, qualities and integration into participants' self-management.

2.3 MATERIALS AND METHODS

2.31 OBJECTIVE

The primary objective of this systematic review is to summarize the characteristics and features of mHealth Apps for self-management in people with chronic lung diseases described in RCTs.

2.32 METHODS

A protocol was developed and registered on PROSPERO (CRD42021260205) as of July 10, 2021. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Guideline [24] was used to direct and report this review (Supplementary Material, Table 1).

2.33 DATA SOURCES AND SEARCH

A structured search strategy was developed to identify relevant citations across five online databases: CINAHL (EBSCOHost), Medline, Embase, Scopus and Cochrane Libraries. A combination of medical subject headings (MeSH) and key terms related to 1) mobile health apps; 2) chronic lung disease; and 3) self-management were combined with Boolean operators. The MeSH and keywords were modified for each database (Supplementary Material, Table 2). Each database was searched from inception to June 2021 and updated in May 2022. Reference lists of eligible studies were screened and if the app's name was reported, they were used as keywords to

search for related studies. If full-text citations were unavailable, authors were contacted for further information.

2.34 STUDY SELECTION

The search results were compiled and uploaded onto Clarivate Endnote X9.1 (Philadelphia, Pennsylvania) Reference Manager to remove duplicates. Titles and abstracts were screened by three reviewers (SQ, WM, AM) on Research Screener [25], a machine learning tool, to increase screening efficiency. Research screener is a validated Web-based application that semi-automates abstract screening by utilizing an algorithm developed from machine learning methods [25]. Research Screener access and details have been previously published [25]. Full-text screening to identify eligible articles were completed by two reviewers (SQ, WM) on Covidence (Veritas Health Innovation, Australia). Disagreements were resolved by a fourth reviewer (AO). For the updated search in May 2022, Covidence was used to screen abstracts and review full-text articles amongst two reviewers (SQ, WM), and any disagreements were resolved by AO.

Studies were included if they were: 1) RCTs; 2) investigating mHealth Apps for disease self-management; 3) in adult participants (≥18 years) with chronic lung disease. Chronic lung disease included, but were not limited to asthma, bronchiectasis, COPD, cystic fibrosis, interstitial lung disease, idiopathic pulmonary fibrosis, lung cancer, pulmonary hypertension, sarcoidosis, asbestosis, or asthma-COPD overlap syndrome. MHealth app for self-management were defined as mobile apps that were easily accessible on mobile devices (i.e., phones or tablets), not including web-based platforms [8], with features to help patients engage in activities to manage their condition [13,26]. Additionally, publications had to be published in English, French or Portuguese, in alignment with the research teams' language capabilities. Articles were excluded if mHealth Apps did not have interactive components (e.g., communication, monitoring only) or

were trialed in the pediatric population or published in languages other than English, Portuguese or French.

2.35 DATA EXTRACTION AND ASSESSMENT CRITERIA

Data was extracted by one reviewer (AB) and verified by a second reviewer (SQ or WM). Extracted data included: authors, publication dates, study design, participants' characteristics, clinical outcomes, and mHealth description (i.e., designs and implementation), listed in Supplementary Material. Their characteristics and features were extracted using the mHealth Index and Navigation Database (MIND) evaluation framework [27,28], described by Lagan et al.[26] This framework has excellent interrater reliability (kappa ≥0.75), informed by 45 different app evaluation models to create 107 objective questions across five domains [28].

Supplemental files and other referenced publications (where applicable) were retrieved to facilitate data extraction. For example, one MIND question required reviewers to use a readability calculator to assess the readability of apps' privacy policies [26,29]. If accessible, apps' privacy policies were retrieved and entered into the recommended readability calculator [26]. The Flesch-Kincaid grade level (FKGL) determines text reading level, useful for identifying suitable resources for patients' education level [30]. The FKGL score is a direct estimate of the grade level that matches the U.S. education grade level (i.e., FKGL scores of 8.0-8.9 indicate completion of grade 8 is required to read the text) [30].

2.36 RISK OF BIAS ASSESSMENT

Since this systematic review did not assess or report on the effectiveness and outcomes of mHealth Apps and given the use of the MIND framework to evaluate the studies, a risk of bias assessment was not deemed relevant. Risk of bias assessments are meant to identify potential

study design and outcome biases [31], where the MIND framework was chosen to specifically evaluate the details of mHealth App intervention, more suitable for this review.

2.4 RESULTS

A total of 95,516 papers were retrieved; 86,033 citations remained after duplicates were removed and 12,905 (15%) articles were screened. The updated search retrieved 7,386 new citations. After applying the eligibility criteria, 16 studies were included (Figure 1). During data extraction, one RCT (North et al, 2020 [32]) reported using a previously created mHealth app, myCOPD (Crooks et al, 2020 [33]). Therefore, MIND assessment was completed using data reported by Crooks et al [33] and North et al [32] for myCOPD. The complete MIND evaluations are available in Supplementary Material.

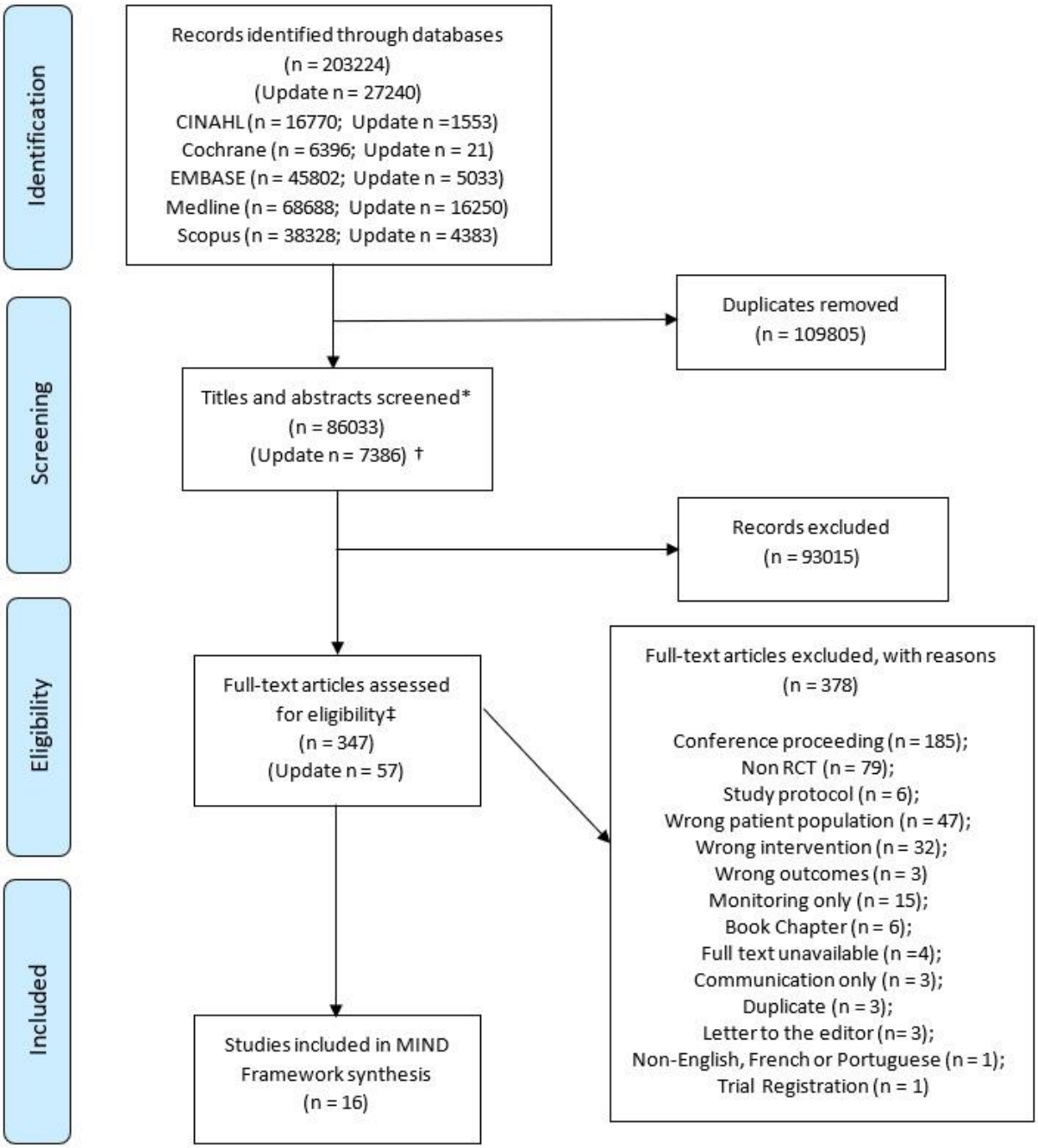

Figure 1: PRISMA Flow diagram for study selection. Original searches were completed in June 2021 and updated searches in May 2022. The updated n reflects search results between June 2021 and May 2022.

2.41 STUDY DETAILS AND PARTICIPANTS

A total 16 studies were included: 11 (69%) reported clinical trial registrations [18,32-41]. Of the 16 studies, there were 15 distinct mHealth apps of: seven for asthma (47%) [18,37-40,42,43] and eight for COPD self-management (53%) [32-36,41,44,45]. Nine (63%) studies reported their app names [18,32,34,36,38-42], and four of these (44%) were findable on the app store (either Android™ or Apple™) [18,32,38,39]. However, none of these apps were downloadable as access was restricted to study participants. Nine apps (60%) [32,34-37,40-42,44] reported their designs were informed by multiple resources, including experts in the field, previous clinical studies and international guidelines; the remaining apps (6, 40%) did not explicitly provide information about their design [18,19,38,39,43,45]. Apps were commonly created with objectives to support self-management, improve medication adherence, provide action plans, control symptoms, facilitate behavioural changes and provide monitoring for clinicians. Studies were conducted in 8 different countries (Netherlands, Turkey, Korea, China, Egypt, Australia, United States of America, United Kingdom) and intervention length varied from 8 to 52 weeks. Frequency of app use was different across studies: participants were instructed to use their apps ad libitum (4, 27%) [18,33,43,45], daily (7, 47%) [32,34-36,39,41,42], weekly (2, 13%) [40,44], for specific circumstances (1, 7%) [38] and one study did not specify usage (7%) [37]. Different apps and their respective studies reported a spectrum of patient-relevant outcome measures, including medication adherence, quality of life, spirometry, exercise tolerance, exacerbations, and hospital admissions. Study details are summarized in Table 1.

Studies evaluating apps for patients with asthma had sample sizes ranging from 22 to 461 in the interventional arm, and 11 to 462 in the control arm. Only one study (7%) reported a 12-month follow up period [18]. Retention at follow up ranged from 67 to 97% in the treatment arm and 43 to 97% in the control arm. Participants' mean age ranged from 31 to 49 years, and 32 to

51 years for the treatment and control groups, respectively. Only 1 study provided details about their participants' comorbidities [40].

For COPD-specific apps, sample sizes ranged from 19 to 110 in the interventional arm and 11 to 81 in the control arm. Two studies reported their follow-up periods were 2 and 12 months [34,35]. Retention rate at follow up ranged from 53% to 93% and 55% to 97% in the treatment and control groups, respectively. Ranges of mean age for the treatment group was 62 to 70 years and 63 to 70 years in the control group and five studies reported their participants' comorbidities [19,35,36,41,44]. Additional participant characteristics are in Table 2.

2.42 BACKGROUND AND ACCESS CHARACTERISTICS

Nine studies provided the app with a mobile device (60%) [19,34-38,40,44,45], and six provided access to the app via invitation/registration code (40%) [18,32,39,41-43]. It is unclear when the apps were created, released, and updated since many apps (11, 73%) were not available on the app marketplace. Two studies (13%) mentioned their apps had accessibility features; one (7%) allowed participants to adjust text size [44], and another (7%) provided participants with larger tablets to increase text size for comfortable viewing [46].

Table 1: mHealth apps, sources, description and study characteristics in Asthma and COPD. A total of 15 apps are reported; 1 app was used and trialed by two studies.

Authors, year	Country	App name	Source of information for app design	App description	Study objectives	Intervention length (weeks)	Follow up period (months)	Frequency of use	Outcome measures
Asthma									
Beerthuizen et al., 2020 [1]	Netherlands	PatientCoach	NR	Support continual pulmonary rehabilitation and self-management	Effectiveness of patient-tailored self-management strategy post intervention	52	12	Ad libitum	• AQLQ • ACQ6 • eHealth User engagement • heiQ
Cingi et al., 2015 [2]	Turkey	POPET	NR	Share motivational and educational content; remind patients to take prescribed medications	Effectiveness of app on health outcomes and quality of life	12	/	Ad libitum	• ACT • # app updates • Frequency of app use • Purpose built question rated (0-5) • Number of follow up visits • Number of emergency visits
Kim et al., 2016 [3]	Korea	snuCARE	GINA guideline and interactive action plan	Provided asthma action plan, daily signals about patients' asthma control status	Feasibility of delivering asthma care via app	8	/	Daily	• PFT • ACT • Medication adherence • QoL for adult Korean asthmatics • Purpose built satisfaction questionnaire
Lin et al., 2022 [4]	China	Not specified	In consultation with 32 hospitals across 28 provinces in China	Log and track symptoms, medications, provide feedback and suggestions and educational data	Improvement overall management of asthma	52	/	NR	• MARS-A (<45 for poor compliance) • App adherence • ACT • Mini-asthma quality of life questionnaire • Lung function • Number of hospitalizations
Mahmoud et al., 2022 [5]	Egypt	Clip-tone buddy	NR	Monitor and coach inhaler techniques	Improve patient inhaler techniques	8	/	For every pMDI use	• FEV1% • PEF% • ACT • pMDI inhaler technique errors
Mosnaim et al., 2021 [6]	United States	Propeller Health	NR	Track dosage and time of	Compare self-management and	12	/	Daily	• SABA free days • % of SABA free days

				inhaler use, meant to alert clinicians of worsening asthma control or prolonged periods of non-compliance	medication monitoring via app affects ICS/ SABA use				• Absolute change from beginning/ end • % daily adherence to ICS • Absolute difference from beginning to end • Asthma control improvement • Proportion of participants experiencing exacerbations
Zairina et al., 2016 [7]	Australia	Breathe-easy	National Asthma Council; GINA guideline	Record asthma symptoms and medication usage weekly	Evaluate efficacy of telehealth program via app with a respiratory device for asthma control during pregnancy	24	/	Weekly	• ACQ-7 • mAQLQ • FEV1, FEV6 • Exacerbations • Number of health visits • Oral corticosteroid usage
COPD									
Bentley et al., 2020 [8]	United Kingdom	SMART-COPD	Previous interviews, literature reviews, stakeholders' feedback and usability testing in exploratory trial	App incorporated into pulmonary rehabilitation program, used to encourage participants to maintain physical activity after PR (provides motivation, personalized feedback)	Feasibility and acceptability of SMART-COPD for self-management in physical activity	8	2	Daily	• incremental shuttle walk test • SGRQ • CHAMPS • Ex-SRES • PHQ-9 • CAT • EQ-5D-3L
Boer et al., 2019 [9]	Netherlands	ACCESS	Used a Bayesian model, in collaboration with two pulmonologists at Radboud University Nijmegen Medical Center	Use spirometry, pulse oximetry, temperature, and self-reported symptoms to determine COPD exacerbation risk	Tailor self-management to support efficient self-care without clinicians' help	52	12	Daily	• Unscheduled health visits • Oral corticosteroid/ antibiotic treatments • Exacerbation related self-efficacy • CCQ • EQ-5D • Symptoms changes assessed via TEXAS

Farmer et al., 2017 [10]	United Kingdom	EDGE	Clinical care teams, including clinicians and engineers working in the target population	Identify exacerbations, monitor condition, medication tracking and support psychological well-being	Efficacy of app for self-monitoring and management to improve quality of life and other clinical outcomes	48	/	Daily	• SGRQ-C • EQ-5D • Hospital admissions • Exacerbations • Deaths • BMQ • Medication adherence • Self-reported smoking cessation • Mood via SCL-20 and SCL-10A
Kwon et al., 2018 [11]	Korea	Efil Breath	Collaboration between several medical universities and centers in Korea	Provide mHealth pulmonary rehabilitation to improve daily physical capacity and quality of life	Create rehabilitation management platform to improve physical activity and quality of life	12	/	Daily	• Purpose built usability questionnaire • CAT • 6MWT • mMRC • purpose built satisfaction questionnaire
Crooks et al., 2020 [12]	United Kingdom	myCOPD	Multidisciplinary team of respiratory clinicians and people with COPD	Improve self-management for their condition	Effectiveness in mild, moderate and severe COPD at improving self-management, symptom control, and medication errors	12	/	Ad libitum	• CAT • ≥1 critical inhaler error at 90 days • PAM • SEAMS • EQ-5D-5L • Activity monitoring 7 days at baseline and after study • Satisfaction • Usage • Completion of educational content
North et al., 2020 [13]	United Kingdom, England			Support patients' self-management and for clinicians/ healthcare teams to remotely monitor patients	Efficacy and safety of using app for self-management instead of written plans	12	/	Daily	• CAT • SGRQ • Number of exacerbations • Number of admissions • Number of inhaler technique errors • Times used/ day • Patient activation measure score • HAD
Park et al., 2020 [14]	Korea	Not specified	Consultation with pulmonary physician and nurse research; literature review, educational resources and	Support self-management, self-efficacy and exercise behaviours	Effectiveness of app on self-management behaviours	24	/	Weekly	• UCSD-SOBQ • Profile of Mood States short form • 6MWT • Self-reported time for exercise/ week • Steps/ day • % sedentary time

			existing COPD apps						• % LPA • %MVPA • Medical outcomes study 36-item short-form health survey • SEMCD • CRQ- Mastery • Exit interviews • Emotional informational support subscale of MOS Social Support survey • Alberto Chronic Obstructive Pulmonary Disease Self-care behaviour inventory • # hospital visits • Frequency of app use • Purpose built questionnaire
Vorrink et al., 2016 [15]	Netherlands	Not specified	NR	Tracks physical activity, oximetry, self-reported questionnaires and provides educational modules	Evaluate efficacy of app after 12 week PR program	12	/	Ad libitum	• FEV1 and FVC • 6MWT • Steps/ day • CRQ-SAS • BMI
Wang et al., 2021[16]	China	Not specified	NR	Support self-management	Effectiveness of app for self-management behaviours, quality of life and sustained behaviour change	48	/	Ad libitum	• CAT • CSMS • Self-reported exercise days] • Self-reported duration of exercise/ session • Number of smokers; cigarettes smoked/day

6MWT= 6-minute walk test; ACT= asthma control test; ACQ= asthma control questionnaire; BMI= body mass index; BMQ= Beliefs about medicines; CAT= COPD assessment test; CCQ= clinical COPD questionnaire; CHAMPS= Community healthy activities model program for seniors; COPD= chronic obstructive pulmonary disease; CRQ= chronic respiratory disease questionnaire; CRQ-SAS= chronic respiratory disease questionnaire- self-administered standardized; CSMS= COPD self-management scale; EQ-5D= EuroQol group's 5-dimension health-related quality of life; Ex-SRES= exercise self-regulatory efficacy scale; FEV1= forced expiratory volume in 1st second %; FVC= forced vital capacity; HAD= hospital anxiety and depression scale; heiQ= Health education Impact questionnaire; ICS= inhaled corticosteroids; LPA= light physical activity (minutes/day); (m)AQLQ= (modified) Asthma quality of life questionnaire; MARS-A= medication adherence report scale – Asthma; mMRC= modified Medical Research Council Dyspnea scale;

MOS (Social Support survey)= Medical outcome study; MVPA= moderate to vigorous physical activity (minutes/ day); PAM= patient activation measure; PEF%= Peak expiratory flow %; PHQ-9= Patient health questionnaire-9; PMDI= pressurized medical device inhaler; NR= Not reported; SABA= short acting beta-agonists; SCL-10A= Standard Checklist 10-item Anxiety Measure; SCL-20= Standard Checklist 20-item Questionnaire; SEAMS= Social emotional Assessment/ Evaluation measure; SEMCD= Self-efficacy for managing chronic disease scale; SGRQ= St George's respiratory questionnaire; TEXAS= Telephonic exacerbation assessment system; UCSD-SOBQ= University of California San-diego -Shortness of breath questionnaire; USE=usefulness, Satisfaction, and Ease of use questionnaire.

Table 2: Participants' baseline characteristics for each study (n=16).

		Intervention						Control					
Authors, year	**App name**	**n**	**Dropouts n (%)**	**Age (mean, ±SD; median, range)**	**Gender (F:M)**	**Comorbidities**	**Follow up %**	**n**	**Dropouts n (%)**	**Age (mean, ±SD; median, range)**	**Gender (F:M)**	**Comorbidities**	**Follow up %**
Asthma													
Beerthuizen et al., 2020 [1]	PatientCoach	45	12	46.7±2.3	25: 8	NR	33 (67%)	47	18	44±2.4	20: 9	NR	29 (62%)
Cingi et al., 2015 [2]	POPET	68	8	32±3.7	30: 30	NR	60 (88%)	68	39	34.5±8.2	12: 17	NR	29 (43%)
Kim et al., 2016 [3]	snuCARE	22	0	49 (19, 72)	18: 4	NR	22 (100%)	22	5	51 (34, 62)	6:13	NR	19 (77%)
Lin et al., 2022 [4]	Not specified	461	84	45 (34, 54)	263: 198	NR	377 (79%)	462	113	46 (34, 55)	272:190	NR	349 (76%)
Mahmoud et al., 2022 [5]	Clip-tone buddy	111	11	48.3±9.21	52: 48	NR	100 (91%)	110	10	46.8±7.87	56:44	NR	100 (91%)
Mosnaim et al., 2021 [6]	Propeller Health	75	2	49.3±11.6	60: 15	NR	73 (97%)	25	1	46.06±14.3	20: 5	NR	24 (96%)
Zairina et al., 2016 [7]	Breathe-easy	36	3	31.1±4.7	36	Anxiety (10); thyroid disorder (4)	33 (94%)	36	1	31.8±4.3	36:0	Anxiety (10); thyroid disorder (2)	35 (97%)
COPD													
Bentley et al., 2020 [8]	SMART-COPD	19	9	68 (63, 72)	11: 8	NR	10 (53%)	11	5	66 (66, 70)	6: 5	NR	6 (55%)
Boer et al., 2019 [9]	ACCESS	43	7	69.3±8.8	25: 18	joint disorder 13(30%), cardiac disorders 12(28%), back pain 8(19%), diabetes 3(7%), depression / anxiety 3(7%)	36 (87%)	44	4	65.9±8.9	29: 15	joint disorders 13(30%); cardiac disorders 12(27%); back pain 14(32%); diabetes 3(7%); depression/ anxiety 2(5%)	40 (91%)

Farmer et al., 2017 [10]	EDGE	110	14	69.8±9.1	42: 68	hypertension, osteoporosis, high cholesterol, diabetes, heart disease, depression = 89 (80.9%)	93 (87%)	56	7	69.5± 10.6	34: 22	hypertension, osteoporosis, high cholesterol, diabetes, heart disease, depression = 47 (83.9%)	49 (88%)
Kwon et al., 2018 [11]	Efil Breath	Exercise interactive group (mHealth)						Control group					
		30	6	65 (7)	4:26	27/30 with comorbidities	24 (80%)	28	6	64 (8)	7: 21	24/27 with comorbidities	22 (79%)
								Fixed exercise group					
								27	16	64 (8)	4: 23	25/27 with comorbidities	11 (60%)
North et al., 2020 [13]	myCOPD	20	3	65.1±6.3	7: 13	NR	17 (85%)	21	3	68.1± 7.4	10:11	NR	18 (86%)
Crooks et al., 2020 [12]		29	5	65.9±7.3	18:11	NR	24 (90%)	31	1	66.4± 7.0	11:20	NR	30 (97%)
Park et al., 2020 [14]	Not specified	23	1	70.45±9.4	3: 19	<2 comorbidities = 4; ≥2 comorbidities = 18	22 (93%)	20	2	65.1± 11.1	6: 14	<2 comorbidities =8; ≥2 comorbidities = 12	18 (90%)
Vorrink et al., 2016 [15]	Not specified	102	17	62 (9)	42: 42	NR	85 (86%)	81	9	63 (8)	37: 36	NR	72 (89%)
Wang et al., 2021 [16]	Not specified	39	4	63.2±7.5	13: 26	Hypertension (21/78); heart disease (12/78); T2D (9/78)	35 (87%)	39	6	64.4±7	10:29	Hypertension (21/78); heart disease (12/78); T2D (9/78)*	33 (85%)

SD= standard deviation; NA = not applicable; NR= not reported; POPET= physician on call patient engagement trial

*combined comorbidities of both control and interventional groups

2.43 DATA SAFETY AND PRIVACY

The privacy policies were available in 4/15 (27%) apps were accessible through their app store page or website (i.e., PatientCoach,[18] Propeller Health [39], Clip-tone buddy [38], myCOPD [36]). Readability of the privacy policies of these apps resulted in FKGL scores from 8 to 15.

Regarding data usage and privacy, eight apps reported they declared data use to their participants (53%)[18,32,36,38,39,41,42,44] and seven declared use of their personal information (47%) [18,32,36,38,39,41,42]. Three (20%) apps mentioned users could opt out of data collection [18,36,39], and four (27%) apps allowed users to delete their own data [18,32,38,39]. Twelve apps (80%) appeared to store their data on their server [18,19,34-42,45], seven (47%) described their security systems [32,36,38-42], and three (25%) mentioned data sharing to third parties [32,38,39]. Data safety and privacy details are summarized in Table 3.

Table 3: Data safety and privacy features and details of the trialed apps (n=15).

Authors, year	App name	Privacy policy available?	Reading level of privacy policy*	Declares data use	Describes use of personal information	Opt out of data collection by user	Data can be deleted by user	Data stored on server	Data stored on device	Security systems described	Collect, use and transmit sensitive data securely	Data sharing to 3rd parties
Asthma												
Beerthuizen et al., 2020 [1]	PatientCoach	✓	11	✓	✓	✓	✓	✓			✓	
Cingi et al., 2015 [2]	POPET											
Kim et al., 2016 [3]	snuCARE			✓	✓			✓		✓	✓	
Lin et al., 2022 [4]	Propeller Health	✓	14.6	✓	✓	✓	✓	✓	✓	✓		✓
Mahmoud et al., 2022 [5]	Not specified							✓				
Mosnaim et al., 2021 [6]	Clip-tone buddy	✓	8.2	✓	✓		✓	✓	✓	✓	✓	✓
Zairina et al., 2016 [7]	Breathe-easy							✓	✓	✓		
COPD												
Bentley et al., 2020 [8]	SMART-COPD							✓				
Boer et al., 2019 [9]	ACCESS							✓				
Farmer et al., 2017 [10]	EDGE			✓	✓	✓		✓		✓	✓	
Kwon et al., 2018 [11]	Efil Breath			✓	✓			✓		✓	✓	
Crooks et al., 2020 [12]; North et al., 2020 [13]	myCOPD	✓	12.5	✓	✓		✓	✓		✓	✓	✓
Park et al., 2020 [14]	Not specified			✓								
Vorrink et al., 2016 [15]	Not specified							✓				
Wang et al., 2021[16]	Not specified											

COPD= chronic obstructive pulmonary disease; POPET= physician on call patient engagement trial

*Flesch-Kincaid Reading Level

2.44 APP EFFECTIVENESS AND CLINICAL FOUNDATION

The context of this domain is to assess apps for their clinical foundation and effectiveness in the intended population [26]. Five apps (33%) had additional peer-reviewed publications to describe the effectiveness or feasibility of their apps [32,35,36,39,41]. App effectiveness data are outlined in Table 4.

Table 4: Clinical data to support apps' effectiveness and clinical foundation.

Authors, year	App name	Effectiveness, efficacy, usability and/ or feasibility evidence for its use
Asthma		
Beerthuizen et al., 2020 [1]	PatientCoach*	NR
Cingi et al., 2015 [2]	POPET	NR
Kim et al., 2016 [3]	snuCARE	NR
Lin et al., 2022 [4]	Not specified	NR
Mahmoud et al., 2022 [5]	Clip-tone buddy*	NR
Mosnaim et al., 2021 [6]	Propeller Health*	Variety of peer-reviewed publications listed on Propeller Health's website
Zairina et al., 2016 [7]	Breathe-easy	NR
COPD		
Bentley et al., 2020 [8]	SMART-COPD	NR
Boer et al., 2019 [9]	ACCESS	Validation study – Boer et al., 2018
Farmer et al., 2017 [10]	EDGE	RCT protocol – Farmer et al 2014 Pilot study – Shah et al., 2014 6-month cohort evaluation study – Hardinge et al., 2015 Technical report of EDGE – Velardo et al., 2017
Kwon et al., 2018 [11]	Efil Breath	NR
Crooks et al., 2020 [12]; North et al., 2020 [13]	myCOPD*	Effectiveness in pulmonary rehabilitation (RCT) – Bourne et al., 2017 Feasibility trial (abstract) – North et al., 2018 Feasibility study – Cooper et al., 2022 Variety of peer-reviewed publications listed on mymHealth website
Park et al., 2020 [14]	Not specified	NR
Vorrink et al., 2016 [15]	Not specified	Feasibility study – Vorrink et al., 2016 Perceptions of the mHealth tool – Vorrink et al., 2017
Wang et al., 2021[16]	Not specified	NR

COPD= chronic obstructive pulmonary disease; POPET= physician on call patient engagement trial; NR= not reported; *Searchable in the app store (either Google Play or Apple App store)

2.45 USER EXPERIENCE AND ENGAGEMENT

Across the different apps, they vary in their input requirements, output data, engagement styles and features. None of the apps reported whether access to participants' contact lists, cameras, or microphones were required for use. Common input requirements were questionnaires (8, 53%) [18,32,36,37,41-44], journaling (7, 47%) [18,32,36,41-44], step tracking (6, 40%) [18,32,34,36,44,45], and data from external hardware (9, 67%) [18,32,34,35,39-42,44]. Ten apps (67%) provided participants with information and resources for educational purposes [18,19,32,34,36,37,42-45], seven had push notifications (47%) [18,32,39,41-44], and three had reminders (20%) [18,39,41]. Five apps reported graphical visualizations (33%) [32,34,41,44,45], four with text summarizations (27%) [34,36,39,45]. Two apps allowed data sharing to users' social media accounts (13%) [42,43]. Five of these apps (33%) had features allowing participants to connect with healthcare providers remotely, through messaging [39,43,47], and phone calls [36,44].

Eleven apps had features to support collaborations between participants and healthcare professionals (73%) [18,32,34,36,37,39,41-45]. Six apps (40%) had content delivered to participants in video-formats for educational or motivational purposes [19,32,36-38,44]. Participants could use the apps to send messages to peers or healthcare professionals (4, 27%) [19,43-45], or to network with peers (13%) [19,44]. Other features were to support participants in setting goals (9, 60%) [18,19,32,34,36,42-45], tracking medications (7, 47%) [32,37-41,43], exercise (7, 47%) [18,19,32,34,41,44,45], mood (7, 47%) [32,35,36,41-44] or mindfulness (2, 13%) [32,36]. Details of each apps' user engagement and style are reported in Table 5.

Table 5: The input, output data for each app, and their engagement style and features. For a full list, see Supplementary Material.

		Input						Output							Engagement style										Features					
Authors, year	**App name**	**Surveys**	**Journaling or diary**	**location services**	**Steps tracking**	**External hardware**	**Connection to social media accounts**	**Notifications from app**	**Information and references**	**Sharing to social media**	**Set reminders**	**Graphical data**	**Summaries of collected data**	**Connection to licensed healthcare**	**Chat/ Messages**	**Screener tool**	**Real-time responses**	**Asynchronous responses**	**Videos**	**Audio**	**AI support**	**Peer support**	**Collaboration with healthcare team**	**Medication tracking**	**Mood tracking**	**Exercise tracking and suggestions**	**Goals and action plans**	**Didactic education**	**Mindfulness exercises**
Asthma																														
Beerthuizen et al., 2020 [1]	PatientCoach	✓	✓		✓	✓		✓	✓		✓					✓							✓			✓	✓	✓	
Cingi et al., 2015 [2]	POPET	✓	✓					✓	✓	✓				✓	✓	✓	✓	✓					✓	✓	✓		✓	✓	
Kim et al., 2016 [3]	snuCARE	✓	✓			✓		✓	✓	✓						✓		✓					✓		✓		✓	✓	
Lin et al., 2022 [4]	Not specified	✓							✓							✓			✓				✓	✓				✓	
Mahmoud et al., 2022 [5]	Clip-tone buddy																		✓	✓ *				✓					
Mosnaim et al., 2021 [6]	Propeller Health			✓		✓	✓	✓			✓		✓	✓									✓	✓					
Zairina et al., 2016 [7]	Breathe-easy					✓																		✓					
COPD																														
Bentley et al., 2020 [8]	SMART-COPD				✓	✓			✓			✓	✓	✓									✓			✓	✓	✓	
Boer et al., 2019 [9]	ACCESS					✓																			✓				
Farmer et al., 2017 [10]	EDGE	✓	✓		✓				✓				✓	✓		✓			✓				✓		✓		✓	✓	✓
Kwon et al., 2018 [11]	Efil Breath	✓	✓			✓		✓			✓	✓				✓							✓	✓	✓	✓			

Crooks et al., 2020 [12]; North et al., 2020 [13]	myCOPD	✓	✓		✓**	✓**		✓	✓			✓				✓			✓		✓		✓	✓	✓	✓**	✓	✓	✓
Park et al., 2020 [14]	Not specified	✓	✓		✓	✓	✓	✓	✓			✓			✓	✓	✓†	✓†	✓			✓	✓		✓	✓	✓	✓	
Vorrink et al., 2016 [15]	Not specified				✓				✓			✓	✓	✓	✓			✓					✓			✓	✓	✓	
Wang et al., 2021[16]	Not specified								✓						✓		✓†	✓†	✓			✓				✓	✓	✓	

*Audio-visual feedback heard when utilizing external device (pMDI) with app. **Crooks et al used Fitbit to track steps. †App provides a chatroom and portal for participants to network with peers, and seek assistance from healthcare providers – it was NR whether this was live or asynchronous.

COPD= chronic obstructive pulmonary disease; POPET= physician on call patient engagement trial

2.46 DATA INTEGRATION AND THERAPEUTIC ALLIANCE

Seven studies (47%) stated that their apps must be used with the healthcare or research team [18,32,34,36,39,41,42], or else access to the apps were not permitted. None of the studies provided clear indications on whether participants owned their data. Two apps (13%) mentioned that participants could export their data [32,41], and four apps (27%) could send data to users' electronic medical records [35,36,39,41]. Details are reported in Table 6.

Table 6: Usage and data interoperability of the 15 apps – all the apps were designed to be a self-management tool and patient-facing.

		Usage		Interoperability and Data sharing	
Authors, year	**App name**	**Self-help and self-management tool**	**Must be used with clinical team**	**Data export available to users**	**Data can be sent to EMR**
Asthma					
Beerthuizen et al., 2020 [1]	PatientCoach	✓	✓		
Cingi et al., 2015 [2]	POPET	✓			
Kim et al., 2016 [3]	snuCARE	✓	✓*		
Lin et al., 2022 [4]	Not specified	✓			
Mahmoud et al., 2022 [5]	Clip-tone buddy	✓			
Mosnaim et al., 2021 [6]	Propeller Health	✓	✓ **		✓
Zairina et al., 2016 [7]	Breathe-easy	✓			
COPD					
Bentley et al., 2020 [8]	SMART-COPD	✓	✓		
Boer et al., 2019 [9]	ACCESS	✓			✓
Farmer et al., 2017 [10]	EDGE	✓	✓	✓	✓
Kwon et al., 2018 [11]	Efil Breath	✓	✓	✓	✓
Crooks et al., 2020 [12]; North et al., 2020 [13]	myCOPD	✓	✓		
Park et al., 2020 [14]	Not specified	✓			
Vorrink et al., 2016 [15]	Not specified	✓			
Wang et al., 2021[16]	Not specified	✓			

*used with research team; **used under supervision

COPD= chronic obstructive pulmonary disease; EMR = electronic medical record; POPET= physician on call patient engagement trial

2.5 DISCUSSION

In this review, 15 mHealth apps were trialed in 16 RCTs with inconsistent reports of designs and characteristics. Intervention lengths, follow up periods, and frequency of use varied considerably among the studies, with designs being informed from multiple sources. Most studies did not provide sufficient information to complete most of the domains in the MIND framework. Information regarding engagement and features for clinical use was frequently reported, with common features being education, symptom tracking, medication reminders and clinical support. There was a lack of information on background information and characteristics with no direct access to the apps such that it was unclear whether most of these apps were being evaluated or how often they were updated. Additionally, there were minimal details about their privacy and security functions as well as scant discussion regarding the apps' clinical foundation.

Data privacy was a difficult domain to access across studies although it is an important determinant of acceptability and clinical use [4,5,10]. Available privacy policies had FKGL scores ranging from 8 to 15, indicating the reading level required to understand these privacy policies were at the level of high school completion. It is important for users to understand how their personal information and data are handled prior to using mHealth apps [26,48], and is recommended that this information be written at the grade 8 level or lower to accommodate their users [30]. This is imperative as these resources must be readable and understandable to facilitate users' self-management [30].

The RCTs included in this review investigated mHealth apps in asthma and COPD specifically. Compared to past systematic reviews, this review aimed at systematically reviewing the reported app designs and characteristics that were rarely evaluated and reported before. From our MIND assessment, we were able to identify in-depth differences in the interventions' foundational designs, features, engagement styles and intended use. In three apps for asthma self-

management, they did not provide features for education, but were meant to facilitate medication tracking, in conjunction with external hardware, i.e., puffers with sensors [38-40]. The remaining four apps seem to primarily provide didactic education, and symptom monitoring, along with additional features to journal, receive notifications and collaborations with clinicians [18,37,42,43]. In the context of COPD, one study using ACCESS mentioned the app was created to explicitly for detect and guide patients during COPD exacerbations [35]. Whereas the other COPD apps appear to provide combinations of didactic education, symptoms tracking, exercise encouragement and collaborations with clinicians [19,32-34,36,41,44,45,47]. Two key components that appear frequently across these apps are the interactive feedback and the possibility to collaborate with their healthcare teams, features well suited to optimize acceptability and implementation amongst patients [3,9,49]. However, the apps in these RCTs may have the potential to provide additional designs or features not discussed here as this study was limited to synthesizing the information that was inconsistently reported across studies.

There is a clear need to emphasize the lack of information and knowledge growth on these app interventions after their RCTs. Of the 15 apps identified in this review, four were searchable on the app marketplace, but only two had public websites (Propeller Health and myCOPD) [32,33,39]. These two mHealth app development teams have continued to assess their apps' effectiveness in different subgroups, with clear outlines of their ongoing research, publications and presentations available to the public (Propeller Health, https://propellerhealth.com/clinical-research/published-research/ ; and myCOPD, https://mymhealth.com/studies). This open communication is ideal, as it provides clarity to their target users and can support future collaborations with academic centers to strengthen the understanding of whether these apps are designed well and suitable for self-management in

chronic lung disease. Unfortunately, the remainder of apps did not identify additional clinical evidence to support their use and some studies did not report their app name, see Table 4 [19,37,44,45]. In consideration of these factors, it is unclear whether these apps are still in use, being trialed or updated frequently, warranting hesitations of generalizing these findings into clinical practice. Currently, the mHealth space needs consistency in their app interventions, which may be addressed if there is transparency and continued efforts to build on the body of evidence of established apps, similar to Propeller Health and myCOPD.

There are uncertainties with using mHealth apps for facilitating chronic respiratory care, though mHealth apps may have the potential to promote self-management, improve physical activity and quality of life [22,50,51]. From our MIND assessment across the 15 distinct apps trialed in RCTs, it is apparent that the app designs and features varied considerably and were underreported, likely preventing their results from being reproduced and generalizable to other apps and populations. This trend may explain the variable effectiveness shown in past systematic reviews, where mHealth apps in people with COPD or asthma reported high heterogeneity in the included studies [7,20-22,50]. Therefore, standardizing these interventions are necessary to ensure their quality, including their method for implementation, monitoring and outcome assessments [22,51]. Ensuring consistency in the quality of these interventions continues to be a challenge, as there are significant variations in design elements and of quality assessment tools for mHealth apps in the chronic disease space [23]. There is a need for future research to utilize a standardized approach to ensure their interventions are created with equal quality [22,23]. Of all the available app evaluation tools that exist, the MIND framework demonstrated in this review and in the mental health space [52], that its extensive comprehensiveness can likely ensure all potential domains of app quality are accounted for [26,28]. Since the MIND framework was informed by a compilation of

many existing mHealth app models, it could serve as a checklist to ensure the quality control of the mHealth app interventions created and reported, specifically regarding their foundational design, features and interactive components in future studies [26,28].

Our review has several strengths. To our knowledge, this is the first time a systematic review used an established framework to describe reported characteristics of mHealth apps for chronic lung diseases in RCTs. The MIND framework is comprehensive [26], guiding the assessments of essential apps designs and characteristics. Furthermore, we sought additional resources to ensure we thoroughly completed the MIND assessment for each mHealth App. Another strength of our study is the extensive search strategy we implemented and updated to ensure all possible studies were screened for inclusion. With Research Screener [25], we efficiently screened a large volume of citations. Research Screener's sensitivity threshold ranges between 4% to 32%, and past systematic reviews reported all relevant articles were found after 15% of imported records were screened, similar to our screening total [25].

This study has a few limitations. Although our search strategies led to a large volume of results, it was necessary to use these key terms to ensure all the possible articles were found as taxonomy for this technological intervention is inconsistent. To facilitate the process, Research Screener was used [25]. Another limitation is the lack of access to these apps; some were found on the app marketplace but required special access, while others were simply described in their reports with visual screenshots.

2.6 CONCLUSION

This review described mHealth interventions' design, qualities, and characteristics available in RCTs using a comprehensive framework. These findings demonstrated the differences between mHealth Apps across trials, and the potential challenges healthcare

providers may have in identifying the most suitable app to integrate into clinical care plans. This review emphasized the need for intervention consistency and reporting, and the benefits of using the MIND framework to guide future app development and reporting. Advocating for the use of the MIND framework will minimize intervention heterogeneity in future studies, strengthening their qualities and evidence to facilitate our understanding of their effectiveness in self-management for chronic lung disease.

2.7 SUPPLEMENTARY DATA

For supplementary tables and documents, please follow the link: Chapter 2 Supplementary data

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CHAPTER 3: COPD APP MARKETPLACE

Features and characteristics of publicly available mHealth apps for self-management in chronic obstructive pulmonary disease

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Features and characteristics of publicly available mHealth apps for self-management in chronic obstructive pulmonary disease

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3.1 ABSTRACT

Mobile health applications (mHealth apps) may be able to support people living with chronic obstructive pulmonary disease (COPD) to develop the appropriate skills and routines for adequate self-management. Given the wide variety of publicly available mHealth apps, it is important to be aware of their characteristics to optimize their use and mitigate potential harms.

Objective: To report the characteristics and features of publicly available apps for COPD self-management.

Methods: MHealth apps designed for patients' COPD self-management were searched in the Google Play or Apple app stores. Two reviewers trialed and assessed the eligible apps using the MHealth Index and Navigation Database framework to describe the characteristics, qualities, and features of mHealth apps across five domains.

Results: From the Google Play and Apple stores, thirteen apps were identified and eligible for further evaluation. All thirteen apps were available for Android devices, but only seven were available for Apple devices. Most apps were developed by for-profit organizations (8/13), non-profit organizations (2/13) and unknown developers (3/13). Many apps had privacy policies (9/13), but only three apps described their security systems and two mentioned compliance with local health information and data usage laws. Education was the common app feature; additional features were medication reminders, symptom tracking, journaling and action planning. None provided clinical evidence to support their use.

Conclusions: Publicly available COPD apps vary in their designs, features, and overall quality. These apps lack evidence to support their clinical use and cannot be recommended at this time.

3.2 INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is one of the leading causes of disability, morbidity and mortality,[1,2] negatively impacting people's overall quality of life and well-being.[3,4] In 2019, it was estimated that 391.9 million people aged 30-79 years had COPD worldwide, an increase from the reported estimate of 299.4 million in 2017.[5] Although many treatment options are available, the burden of living with COPD is an ongoing challenge, especially in middle to lower class income countries.[6] Individuals with COPD are challenged to live with a progressive condition, have needs beyond pharmacologic therapy,[7] and would benefit from self-management.[4] With greater attention towards addressing patients' needs, clinicians can employ strategies and provide resources that will empower patients to improve their self-management.[4,8]

The coronavirus-19 (COVID-19) pandemic presented many challenges to people with COPD including social isolation, decreased physical activity and increased anxiety.[9,10] Not only do they have an increased risk for poor clinical outcomes if infected with COVID-19,[11,12] but to mitigate the risk and spread of COVID-19, many of the components of their care became unavailable. Health organizations have endorsed and supported the use of virtual care for COPD to offset accessibility and capacity issues when in-person options were not possible, especially in rural communities.[13-17] As a result, there has been rapid adoption of virtual options such as telehealth, a generic term referring to healthcare services delivered digitally and remotely in various formats.[18,19] Telehealth interventions are used with increasing frequency to assist with the management of chronic conditions such as mental health, cardiovascular disease, stroke and diabetes,[19] However, their adoption into COPD care is limited, but continues to grow, especially since the COVID-19 pandemic.[15-17] One potential and attractive solution is mobile health applications (mHealth apps), mobile computerized portal available on mobile devices.[20]

There are several studies and systematic reviews demonstrating modest benefits of using mHealth apps to facilitate COPD self-management, including improved COPD knowledge and self-care,[21,22] reduced hospital admissions,[20] and increased physical activity.[23] Patients from these trials expressed their interest in continuing to use the applications to support their COPD care.[8,22,24-26] However, these reports were from the use of COPD apps designed and trialed by researchers and clinicians,[21,23,25,27,28] with many not available to the public,[29] and may not be applicable to freely available COPD apps. Features available in public COPD apps vary, with the most common for general education, symptom tracking, reminders or diary keeping.[30] These public COPD apps are easily accessible to those seeking resources to help manage their COPD, but the absence of agreed standards or quality controls may allow incorrect information, wide content variation or inappropriate feedback: all of which are safety concerns that could endanger users' health.[29,31] The rapid growth and continuous changes of the app marketplace have led to the development of tools to assess the quality and effectiveness of mHealth apps.[32,33]

Many app evaluation tools are available to ensure mHealth apps are verified for their safety, usability and clinical relevance.[32] In contrast, technical considerations (i.e., last update, privacy and security qualities) are less likely to be assessed for.[34] However, an actionable evaluation tool called the mHealth Index and Navigation Database (MIND) framework was developed by Lagan et al.[33] to comprehensively assess mHealth apps on their designs and features across multiple domains. The MIND framework was derived from 45 existing app evaluation frameworks, and has excellent interrater reliability (kappa $\geq$0.75).[32] There are 107 objective questions in the MIND framework,[32] categorized into five assessment domains: 1) Background and access; 2) Data safety and privacy; 3) App effectiveness and clinical foundation; 4) User experience and engagement; 5) Data integration towards therapeutic alliance.

The ultimate goal of the MIND framework is to compile mHealth app evaluations onto an open database for mental health apps by the Beth Israel Deaconess Medical Center, Medical Center, Harvard University.[32,33] Apps logged in the database have their MIND assessments publicly available, detailing the apps' characteristics, features, supporting clinical evidence or endorsement for use.[35] However, the MIND framework can be used and applied into mHealth apps for other chronic diseases and conditions.[32] Therefore, there is an opportunity to evaluate the quality of publicly available COPD self-management apps to provide guidance to health care professionals to determine the apps' most appropriate use.[33]

3.3 OBJECTIVES

The primary objective of this evaluation study was to report the features and characteristics of publicly available apps for COPD self-management using a comprehensive app evaluation framework.

3.4 METHODS

We systematically searched for COPD self-management apps in both Apple and Google Play (Android) app stores. These two app stores were chosen as they have the biggest collections of apps, with over two and three million apps available for download in Apple and Google Play, respectively. Eligible apps were assessed using the mHealth Index and Navigation Database (MIND) framework (described in detail below).[32]

3.41 SEARCH STRATEGY

The research team, comprised of healthcare researchers and professionals with expertise in COPD, determined the key search terms. The keywords used for the searches were: *COPD, chronic obstructive pulmonary disease, chronic bronchitis, emphysema.* The keywords were kept broad for the purposes of ensuring that any COPD-directed app was found for screening. The

two app stores were searched on December 2021 and search results were updated regularly (search results re-checked every 1-2 months) until August 2022. All searches were performed in Toronto, Canada.

3.42 INCLUSION AND EXCLUSION CRITERIA

Apps were included if they incorporated features aimed at facilitating self-management for people with COPD i.e., activities for self-help or to support patients' understanding and skills in managing health.[36] In addition, mHealth had to be patient-facing, available in English and free to download. Only free to download apps were included as the aim was to evaluate easily accessible apps, as associated cost with mHealth use is a reported barrier to their adoption.[26,37] Apps were excluded if they were designed primarily for healthcare providers rather than public use. Additional exclusions included app restriction by countries or regions, technical issues (unable to download after two attempts by both reviewers), non-COPD related apps (i.e., for other health conditions), and apps that were non health or wellness related. Non-COPD related apps were defined as apps that did not provide exclusive self-management features or education for people living with COPD. Apps that were designed to target users with any lung condition, not explicit to COPD, were excluded, as the aim was to assess apps that were clearly designed for people living with COPD.

3.43 SCREENING AND APP SELECTION

Results for each search term in both app stores were recorded. Microsoft Excel was used to organize and track the search results and screening process. Duplicate apps were removed prior to screening by the two independent reviewers (SQ and AB). Each app was screened against the inclusion criteria by the two reviewers independently, using the app stores' descriptions and screenshots to determine the app's suitability for further assessment. Apps were

labelled for *inclusion* or *exclusion*, with a reason provided for exclusion. Discrepancies in the app's eligibility or exclusion reasons were discussed and agreement was reached.

3.44 APP EVALUATION

Apps that met the inclusion criteria after reviewers' deliberation were downloaded onto cell phones (Google Pixel 3, Android version 12 and iPhone, iOS version 16). Reviewers independently evaluated content and features using the extraction data sheet guided by the components outlined in the MIND framework. After individual assessments, results were compared, and discrepancies were resolved by discussion.

3.45 MHEALTH INDEX AND NAVIGATION DATABASE (MIND) EVALUATION FRAMEWORK

Although the formulation of the MIND framework stemmed from the need to verify the quality and features of mental health apps for clinical use, this evaluation tool could be used for apps in other health fields.[32,38] Clarification for each MIND question was previously published by Lagan et al. (2020)[32]; these descriptions were used to facilitate reviewers' data extraction.

Several questions in the MIND framework required evaluators to retrieve information externally from the app platforms. Questions under the *App origin, characteristics and accessibility* asked for the app's size, operating system, ratings, release date, last update and ratings, information available on the app's download page of the app marketplace. Another question requiring external resources to answer were related to *Privacy and Security.* The readability of the apps' privacy policies was calculated using an online readability calculator. [32,39,40] The recommended readability test outlined in the MIND framework is the Flesch-Kincaid grade level (FKGL), a commonly used scale by healthcare professionals to identify reading level appropriate resources for patients.[32,41] The FKGL determines text readability using the average sentence length and word length and the derived score provides an estimated grade level

matching the U.S. education grade level.[42] For example an FKGL score of 8.0-8.9 means the text is readable to people who completed grade 8.[41,42]

3.45 DATA EXTRACTION AND ASSESSMENT

For each question, responses were recorded as: 0 for no; 1 for yes; 2 for unsure or unknown; and 3 for not applicable. Since the MIND framework does not provide a final rating score, a rating scale was utilized by the reviewers to grade the apps' potential in clinical use. However, user ratings from either the Apple or Google Play stores were extracted as part of the MIND framework assessment. In addition, reviewers provided each app a score to demonstrate their endorsement or lack of, using a 5-point Likert scale. This rating scale was developed by Camacho et al, as part of their mHealth app assessment and implementation framework, for raters to grade apps for their potential clinical use.[38] The scores ranged from 1 - "I would not recommend this app to anyone" to 5 – "I would recommend this app to everyone".[38] Means and their respective ranges were calculated and App counts and percentages of total were reported for each question.

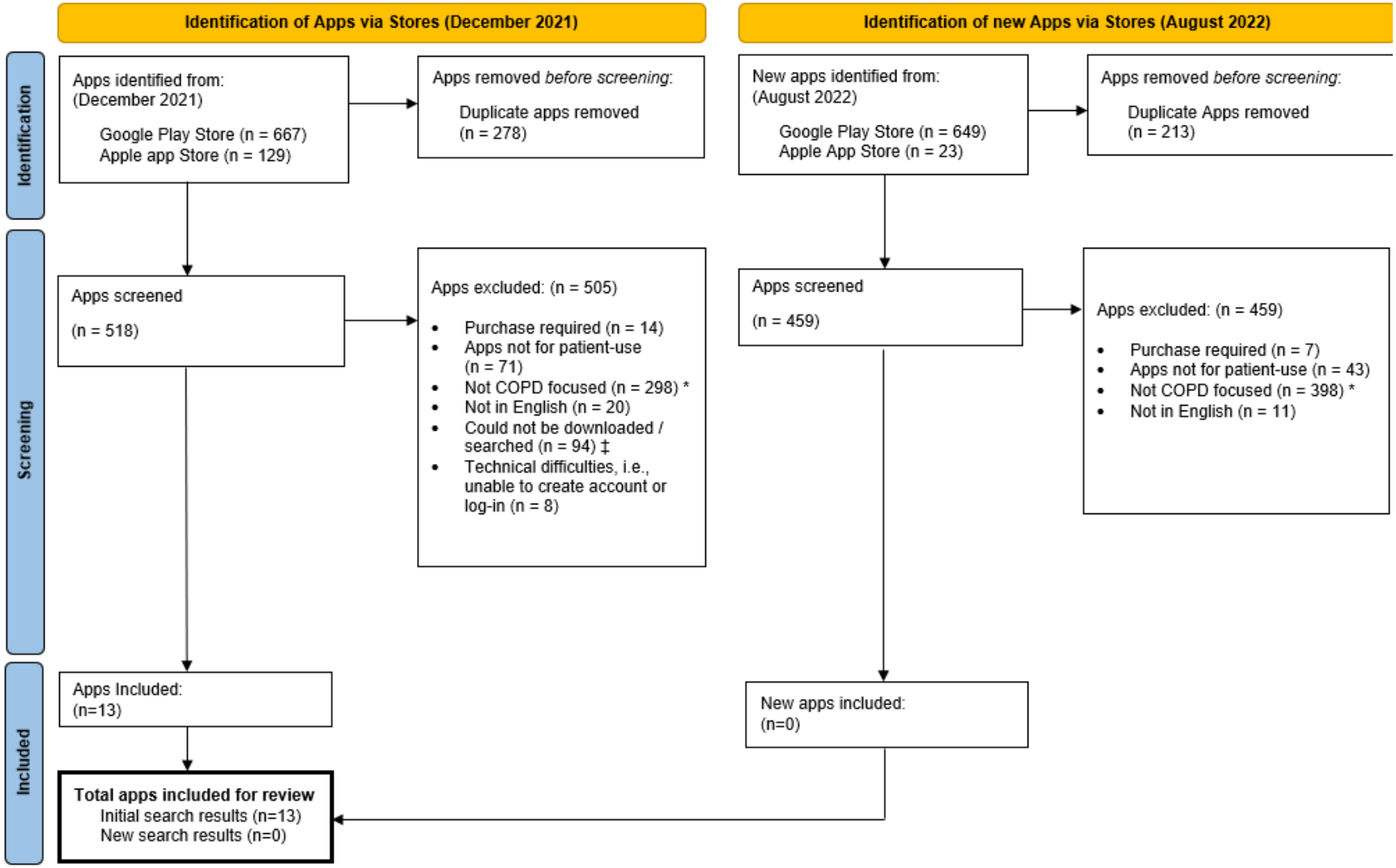
3.5 RESULTS

3.51 SEARCH RESULTS

A total of 1316 apps from the Google Play Store and 152 apps from the Apple App Store were found using the different search terms at two different time points. After 491 duplicates were removed, 977 were screened by the two reviewers. Using the apps' descriptions and screenshots to determine eligibility, 964 apps were excluded. A total of 13 apps were eligible and downloaded for further assessment. Five of the apps required sign-up with an email address to gain access to the information and features; a mutual email address was used to create a shared account for reviewers to access these specific apps. However, one app became unavailable during the data collection phase and only one reviewer assessed the app (myCOPD Assistant by

Revitality LLC). The process of searching and including apps for assessment are illustrated in Figure 1.

Figure 2: Flow diagram of the app search and selection at each stage**.**



* Apps that were not targeted towards people living with COPD (i.e., for other diseases or conditions); ‡These apps were identified in the initial search in December 2021 but were no longer available on the Google Play or App store in August 2022 for screening.

5.52 APP ORIGIN, CHARACTERISTICS AND ACCESSIBILITY

The summary of the app origins and accessibility characteristics are described in Tables 1 and 2. Of the 13 identified apps, seven were available from the Google Play Store only and the remaining six were available on both app stores. The minimum operation system required for each of the apps differed: the minimum Apple iOS noted is 9.0 and for Android, 4.0.3. Apps were released on the Google Play and Apple stores from as early as 2013, up to 2020. Only two apps were updated within the last 6 months (as of June 2022) and the remainder (11/13) were last updated from half-a-year up to 5 years ago. Although included apps were free to download, two apps had one-time, in-app purchases to access certain functions or information.

Apps were developed by for-profit organizations (8/13), non-profit organization (1/13), or were of unknown origin (3/13). One app was collaboratively designed by a government agency with a for-profit organization. Many apps could function online and offline (8/13), where features and data entry did not rely on internet connection to operate. Two apps incorporated accessibility features, allowing for text size adjustments, voice to text within the app or provided instructions to modify their phone settings.

Table 7: Highlight of non-content and common content features of the assessed apps. A total of 13 apps were assessed, of which 6 were unavailable on Apple store.

		Non-content features						Content features												
App name	Developer	Android OS requirements	Apple iOs requirements	In-app purchases	Link to Android store	Link to Apple store	Official website	Self management tool†	Symptoms tracking	Action plan	Exercise coaching/ tracking/reminders i.e., step counts	Medication tracking and reminders	Disease Education	Mindfulness and relaxation Education	Free text and journaling features	Data summaries (graphical or written)	Networking features	Data sharing with peers and family	Data sharing with healthcare team	Reference tool‡
COPD support	MyHealth Teams	5 and up	iOS 10 or later		LINK	LINK	LINK	✓					✓		✓			✓		
COPD Pocket consultant	COPD Foundation	8 and up	iOS 11 or later		LINK	LINK	LINK	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓
Chronic obstructive pulmonary disease assessment	Proactiff Digital Healthcare Services	4.0.3 and up	NA		LINK				✓							✓				✓
COPD	Focus Medica India Pvt. Ltd	5.1 and up	NA	✓	LINK			✓					✓							✓
Cliexa-COPD※	Cliexa Inc	5 and up	iOS 9 or later		LINK	LINK	LINK	✓	✓			✓				✓			✓	
Home remedies for COPD	Timshel Digital	4.4 and up	NA		LINK								✓							✓
Book of COPD	Book Free Apps	4.0.3 and up	NA		LINK								✓							✓
NHS Wales: COPDhub	The Institute of Clinical Science and Technology	5 and up	iOS 11 or later		LINK	LINK	LINK	✓	✓	✓	✓	✓	✓	✓		✓				✓

NIH: COPD	Incelligence Inc	7 and up	NA		LINK	[redacted]	✓					✓							✓
Chronic Lung Disease Treatment	Revolxa Inc	5 and up	NA		LINK	[redacted]	✓					✓							✓
myCOPD assistant※	Revitality LLC	No longer available May 2022		✓	LINK	LINK	[redacted]		✓	✓		✓			✓	✓				
Pulmonary scan	Pulmonary Scan	4.4 and up	iOS 10 or later		LINK	LINK	LINK	✓	✓				✓							✓
MHT COPD Selfcare※	Manifold Health Tech USA Inc	No longer available Aug 2022	iOS 10 or later		[redacted]		LINK	✓	✓		✓	✓				✓				
				Total out of 13				9	7	3	3	5	9	1	3	6	1	2	1	9

✓- Yes; Blank – no; NA – not applicable;
†Self-management criterion was satisfied if it fulfills the definition outlined by Lagan et al, 2020[32]
‡Reference tool defined as an app that only provides education and references (defined in the supplementary materials by Lagan et al, 2020[32])
※Apps unavailable on either app stores as of January 2023

Table 8: Details of the Apps' origin and functionality, including their date of release and updates.

App name	Developer	App Creators*	Operates offline	Accessibility features	Updated within 180 days	Release date (mm/yy)	Last Update (mm/yy)	Updated within 180 days	Release date (mm/yy)†	Last update (mm/yy)†
					Google			Apple		
COPD support	MyHealthTeams	FP		✓		11/14	02/20		2015	2020
COPD Pocket consultant	COPD Foundation	NP	✓			10/18	01/20		2013	2021
Chronic obstructive pulmonary disease assessment	Proactiff Digital Healthcare Services	FP	✓			08/19	08/19			
COPD	Focus Medica India Pvt. Ltd	FP				10/16	08/21			
Cliexa-COPD※	Cliexa Inc	FP				03/19	08/21		2018	2021
Home remedies for COPD	Timshel Digital	FP	✓			02/19	02/19			
Book of COPD	Book Free Apps	U	✓			07/17	04/18			
NHS Wales: COPDhub	The Institute of Clinical Science and Technology & NHS Wales	FP/ G	✓		✓	10/19	03/22	✓	2020	2022
NIH: COPD	Incelligence Inc	FP	✓			09/20	04/21			
Chronic Lung Disease Treatment	Revolxa Inc	FP	✓	✓		12/14	06/21			
myCOPD assistant※	Revitality LLC	U				10/20	01/21		?	?
Pulmonary scan	Pulmonary Scan	U	✓			06/20	04/20		2020	2021
MHT COPD Selfcare※	Manifold Health Tech USA Inc	FP				Over 4 years ago	11/17		?	?

✓- Yes; Blank – no; ? – uncertain;

* FP = for profit; NP = non profit; G= Government; U = unknown;

※Apps unavailable on either app stores as of January 2023

5.53 PRIVACY AND SECURITY, AND DATA INTEROPERABILITY

Privacy, security and data interoperability characteristics and qualities are summarized in Table 3. Nine out of the 13 apps had privacy policies available on the developers' website or within the app store's description. Apps' privacy policies had FKGL scores ranging 10 to 17, with a mean of 13.8, illustrating the high reading level required to understand the privacy policy.

Four out of nine apps with privacy policies did not require data entry from users as their main features were for COPD education. From the remaining five apps with privacy policies, four apps declared the data use and purposes while one app did not provide this information. Personal health information (PHI) was defined as any identifiable information such as name, date of birth or health information,[32] and only four apps had clear specifications about data de-identification, anonymization and storage on servers. Two out of the five apps explicitly stated collected data and its usage complied with the Health Insurance Portability and Accountability Act (HIPAA). Details about apps' security system (3/5) and data sharing with third parties (2/5) were rarely mentioned. None of the apps were equipped with features to respond to potential harm or safety concerns.

Many apps were not designed to maximize data interoperability and integration. Two of the 13 apps describe they could be used with users' healthcare providers, or in conjunction with their treatment plans (4/ 13). Two apps mentioned collected data could be exported and one of them stated data can be sent to users' electronic medical records (EMR).

Table 9: Details on the Apps' Privacy and security; and Data interoperability and Integration.

		Privacy and Security features													Data interoperability and integration				
App	Developer	Privacy policy	Reading level of privacy policy (Flesch-Kincaid)	Declaration of data use/ purposes	PHI collection and use*	Claim to meet HIPPA criteria	Anonymization or de-identification of PHI	opt out of data collection	Personal data may be deleted	Data stored on app server	Data stored on user's Device	Security systems described and in place	Data sharing with 3rd parties	Equipped with features to respond to potential harms/ safety concerns†	Data belongs to user	Use with healthcare provider	Export data	Hybrid use (with healthcare team and treatment plan)	Data sent/ stored on EMR
COPD support	MyHealth Teams	✓	14.5	✓	✓	✓	✓	✓	✓	✓		✓			✓				
COPD Pocket consultant	COPD Foundation	✓	14.3	✓	✓		✓	✓	✓	✓	✓	✓			✓		✓	✓	
Chronic obstructive pulmonary disease assessment	Proactiff Digital Healthcare Services		-					✓	✓		✓				✓				
COPD	Focus Medica India Pvt. Ltd	✓	12.6																
Cliexa-COPD※	Cliexa Inc	✓	14.1	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓
Home remedies for COPD	Timshel Digital	✓	14.9																
Book of COPD	Book Free Apps		-																

NHS Wales: COPDhub	The Institute of Clinical Science and Technology	✓	13.7	✓	✓		✓	✓		✓			✓		✓	✓		✓	
NIH: COPD	Incelligence Inc	✓	17.2																
Chronic Lung Disease Treatment	Revolxa Inc	✓	12.3																
myCOPD assistant※	Revitality LLC		-				?	?	?		✓		?		✓			✓	?
Pulmonary scan	Pulmonary Scan	✓	10.2																
MHT COPD Selfcare※	Manifold Health Tech USA Inc		-										?		?				
Average			13.76																

✓- Yes; Blank – no; ? – unable to verify

EMR = electronic medical record; PHI = personal health information

* Collection of data pertaining to the user's personal characteristics and contact information

†A feature that refers to the apps' ability to provide users with help, i.e., hotline phone number, if the user's data is concerning, defined by Lagan et al., 2020.[30]

※Apps unavailable on either app stores as of January 2023

5.53 EVIDENCE AND CLINICAL FOUNDATION

Apps' evidence and clinical foundation details are described in Table 4. Most apps (10/13) had features as advertised on their download page. None of them had feasibility, usability or efficacy studies to support their use. A few apps (5/13) provided users with a warning of use, that users should not replace medical assistance with the apps.[32] After trialing the apps, reviewers found that nine apps provided outdated (updates not within 6 months of this review), incorrect or misleading information about COPD and were classified as potentially harmful[32] as they contained information not aligned with known published guidelines and standards of care. Additionally, two apps did not provide clear information or resources for their content. Whereas NHS Wales: COPDHub by The Institute of Clinical Science and Technology and COPD Pocket Consultant App by the COPD Foundation do allow users to refer to resources provided by licensed healthcare professionals, or from the GOLD guideline,[2] respectively, but the remaining (11/13) apps did not provide information or direct their users to additional resources from known COPD management guidelines.

Six apps had relevant documents describing their qualities and characteristics. COPD Pocket Consultant App, created by the COPD Foundation, was described in a document by the COPD Foundation (non-profit organization in the US) highlighting its features and potential for healthcare plans.[43] COPD Pocket Consultant App was also assessed in two separate studies by Sleurs et al[44] and Bricca et al.[45] Cliexa-COPD by Cliexa Inc. was assessed in Bricca et al[45] and four other apps (COPD by Focus Medica India Pvt. Ltd; Book of COPD by Book Free Apps; Chronic Lung Disease Treatment by Revolxa Inc.; MHT COPD Self-care by Manifold Health Tech USA Inc.) were assessed by Sleurs et al in 2019. [44]

Table 10: Apps' Evidence and Clinical Foundation details.

App name	Developer	Does the app appear to do what it claims to do?	Are there feasibility, usability or efficacy studies?*	What is the highest impact factor for the published studies?**	Can the app cause harm?†	Does the app provide warning of use? ‡	Relevant publication
COPD support	Myhealth teams	✓			✓	✓	
COPD Pocket consultant	COPD foundation	✓	Assessment by Sleurs et al[44] and Bricca et al[45]	Allergy (13.4); JMIR mHealth and uHealth (4.95)		✓	Statement from COPD foundation[43]
Chronic obstructive pulmonary disease assessment	Proactiff Digital Healthcare Services	✓			✓		
COPD	Focus Medica India Pvt. Ltd	✓	Assessment by Sleurs et al [44]	Allergy (13.4)	✓		
Cliexa-COPD※	Cliexa Inc	✓	Assessment by Bricca et al[45]	JMIR mHealth and uHealth (4.95)	?		
Home remedies for COPD	Timshel Digital				✓		
Book of COPD	Book Free Apps		Assessment by Sleurs et al [44]	Allergy (13.4)	✓		
NHS Wales: COPDhub	The institute of clinical science and technology	✓				✓	
NIH: COPD	Incelligence Inc.	✓			✓	✓	
Chronic Lung Disease Treatment	Revolxa Inc.	✓	Assessment by Sleurs et al [44]	Allergy (13.4)	✓		
myCOPD assistant※	Revitality LLC	✓			✓		
Pulmonary scan	Pulmonary Scan	✓			✓	✓	
MHT COPD Selfcare※	Manifold Health Tech USA Inc.	?	Assessment by Sleurs et al [44, 45]	Allergy (13.4)	?		

✓- Yes; Blank – no; n/a – not applicable;

*Studies that have demonstrated the specific apps' effectiveness, usability, feasibility etc.

**The impact factors of the journals where the peer-reviewed publications were pushed (in prior column).

†Potential harms criterion was satisfied if the app made recommendations that did not align with known guidelines, or provided false information, as defined by Lagan et al, 2020.[30]

‡Apps that declare that app usage does not replace medical care – if mentioned, this assessment criteria was met.

※Apps unavailable on either app stores as of January 2023

5.54 APP INPUTS, OUTPUTS, ENGAGEMENT STYLES AND FEATURES

Specific details of each apps' features and engagement styles are outlined in Table 5. Most apps required input from their users using surveys (7/13) and diary logs (3/13). Access to users' geolocation, camera, external devices, contact lists or social media accounts were required in different apps. For app outputs, several provided notifications (5/13), reminders (4/13), numerical (6/13) and visual (4/13) summaries.

Several apps (7/13) engaged with their users by seeking data through questionnaires, usually for COPD symptoms and diagnoses. Apps relayed their information and features using a variety of methods, including chats, videos, and audio functions.

Of the total 20 potential features listed in the MIND Framework, 11 were observed (Table 1). The most common feature was education (9/13), followed by medication reminders (4/13), action plans (3/13), tracking and teaching exercises (2/13), journaling (2/13), connecting to peers (2/13), breathing and mindfulness exercises (1/3), and connecting to healthcare providers (1/13).

Table 11: App characteristics. Information apps require and return to users (input and output), and their overall engagement style (method of relaying information to users). Common features to supplement the apps' engagement are shown in Table 1.

		Input									Output							Engagement				
App name	Developer	Survey	Diary	Geolocation	Contact list	Camera	Microphone	Step count	External devices	Connect to Social network account	Notifications	Psychoeducational references	Post to Social network	Set reminders	Numerical and text summaries	Visual and graphical summaries	Connection to healthcare provider	Chat/ messengers	Screener	Asynchronous responses	Videos	Audio
COPD support	Myhealth teams		✓			✓				✓	✓	✓	✓					✓		✓		
COPD Pocket consultant	COPD foundation	✓	✓								✓	✓		✓	✓			✓	✓	✓	✓	✓
Chronic obstructive pulmonary disease assessment	Proactiff Digital Healthcare Services	✓													✓				✓			
COPD	Focus Medica India Pvt. Ltd																				✓	✓
Cliexa-COPD※	Cliexa Inc	✓													✓	✓	✓		✓			
Home remedies for COPD	Timshel Digital																					
Book of COPD	Book Free Apps																					
NHS Wales: COPDhub	The institute of clinical science and technology	✓									✓	✓		✓	✓	✓			✓		✓	
NIH: COPD	Incelligence Inc.				✓								✓									
Chronic Lung Disease Treatment	Revolxa Inc.																					
myCOPD assistant※	Revitality LLC	✓	✓	✓					✓		✓			✓	✓	✓			✓			
Pulmonary scan	Pulmonary Scan	✓																	✓			
MHT COPD Selfcare ※	Manifold Health Tech USA Inc.	✓									✓			✓	✓	✓			✓			

✓- Yes; Blank – no; n/a – not applicable;

※Apps unavailable on either app stores as of January 2023

5.55 APP RATINGS

The reviewers' ratings for each app are mentioned in Table 6. The range of reviewers' ratings for these apps was 1 (I would not recommend this app to anyone) to 4 (there are many people to whom I would recommend this app). One app, myCOPD assistant (Revitality LLC) only has one reviewer's rating as the app was no longer available for the other reviewer by the time of their assessment. Only two apps were rated 4 (there are many people to whom I would recommend this app), with the remainder apps having scores 3 or less. The average rating for all assessed COPD apps was 2.04, indicating the unlikeliness for these public COPD apps to be highly recommendable. And despite hundreds of downloads, two apps had public ratings available; COPD Pocket Consultant App by COPD Foundation had 5 star ratings from 9 users on the App store compared to 3.8 star ratings from 24 reviewers on the Google Play store, and Chronic Lung Disease Treatment by Revolxa Inc. had 4.8 star ratings from 22 users on the Google Play store.

Table 12: Final app ratings between the 2 reviewers. An average score of all the apps was calculated; many apps were poorly designed, with inadequate peer-reviewed information to be endorsed for use. App and Google Play store ratings are included as well, if available.

App name	Developer	1 I would not recommend this app to anyone	2 There are very few people I would recommend this app to	3 There are several people I would recommend this app to	4 There are many people I would recommend this app to	5 I would recommend this app to everyone	Average score	Apple store ratings*	Android store ratings; downloads
COPD support	Myhealth teams		A	B			2.5	N/A	N/A
COPD Pocket consultant	COPD foundation				A B		4	5.0 (9 ratings)	3.8 (24 reviewers); >5k
Chronic obstructive pulmonary disease assessment	Proactiff Digital Healthcare Services	B	A				1.5		0; >100
COPD	Focus Medica India Pvt. Ltd	A B					1		0; >500
Cliexa-COPD※	Cliexa Inc		A B				2	N/A	N/A
Home remedies for COPD	Timshel Digital	A B					1		0; >500
Book of COPD	Book Free Apps	A B					1		0; >500
NHS Wales: COPDhub	The institute of clinical science and technology				A B		4	0	0
NIH: COPD	Incelligence Inc.	B	A				1.5		0; unknown
Chronic Lung Disease Treatment	Revolxa Inc.		A B				2		4.8 (22 ratings); >1k
myCOPD assistant※	Revitality LLC			A			3	N/A	N/A
Pulmonary scan	Pulmonary Scan	A	B				1.5	0	0; >1k

MHT COPD Selfcare※	Manifold Health Tech USA Inc.	B	A				1.5	N/A	N/A
Average Evaluation score of Eligible Apps for this study			2.04						

A – Reviewer 1; B – Reviewer 2

*Download information not provided on the App store

※Apps unavailable on either app stores as of January 2023

3.6 DISCUSSION

This study highlighted the variability in mHealth app designs, characteristics, and credibility. Features differed among apps, with education and medication reminders being the most common. Most apps did not clearly identify their sources of information, some of which provided incomplete information or secured their information behind pay-walls.[31] These public COPD apps were deemed inadequate and unsuitable for self-management use. Many did not reference credible information,[31,34] or provide frequent updates in parallel with emerging evidence,[46,47] or support data sharing with relevant clinicians.[9,18,22] They also did not align with resources such as peer networking and self-monitoring that would enforce positive behaviours,[30,48] and there was no evidence to determine the effect of their use on behavioural changes.[34] Generally, most apps cannot be recommended for use, and two apps had limited user ratings on their respective pages despite hundreds of downloads.

COPD self-management has been defined by the personalized, multi-component process of engaging and supporting patients to adapt their behaviours and skills to adequately manage their disease.[36] Therefore, features that provide feedback and support patients' understanding of their disease and self-management were identified to be useful in past studies.[20,26,46,47] However, the evaluated apps in this study do not have past studies to support their clinical effectiveness. Most public COPD apps provided features to educate their users of the disease, and possible management options. However, education alone is insufficient for COPD self-management,[49] as the absence of the necessary interactive planning, personalization and support possibly would not elicit behavioural changes.[46,50] Although several public COPD apps had features for symptoms screening and monitoring, they did not provide interactive feedback to help guide and support users to make appropriate behavioural changes and self-care plans. It is crucial for apps to

incorporate components of feedback and collaboration into their features to potentially impact users' health outcomes.[49] These are major contributors to empowering behavioural changes,[23,51] improving health related quality of life,[52,53] physical activity,[54] and overall satisfaction.[55] Unfortunately, these apps were likely not adequately equipped to provide the level of interactive feedback needed to support personalized COPD management.

Privacy violations through shared data with third parties are an important concern in the implementation of mHealth apps.[18,56] This requires users to be cautious as to how they use and share their data, demonstrating the importance of apps having easily understandable and transparent privacy policies.[32] Although many of the apps reviewed included privacy policies (9/13 apps), most were not described sufficiently to meet the security suggestions outlined in the MIND assessment,[35] nor did they identify compliance with Health Insurance Portability and Accountability Act (HIPAA) or its equivalent. Privacy policies provided also required a literacy level of graduate high school (mean FKGL 13.8), even though publicly available information should be at FKGL 8.[42] The effectiveness of the publicly available COPD apps evaluated in this report had not been verified in the clinical setting and only five of the 13 apps stated that their apps should not replace medical care. Such issues of credibility and clinical evidence are frequently of concern by clinicians and patients in knowing which apps might be the most useful in self-management.[26,31,34]

There are a few studies that have assessed public apps for patients living with chronic lung diseases, and reported on their quality and usability using several different measurement tools. In a previous study evaluating apps for chronic lung diseases, Sleurs et al.[44] included a total of 15 COPD-targeted apps (searched in November 2017), where five were available for assessment in our study. Although Sleurs et al. developed and used the Patient Empowerment

through Mobile Technology Index to assess app quality, similar to our results, they found the apps to have overall poor quality.[44] In another review of public apps designed for chronic diseases (searched October 2020), two out of 10 COPD apps were mutually included.[37,45] Using the Mobile App Rating scale (MARS) and App Behaviour Change Scale (ABACUS), Bricca et al reported mediocre quality with poor potential to elicit behavioural changes.[37,45] Other studies have evaluated public apps for specific symptoms experienced by people living with lung diseases, such as breathlessness[29] and promoting mindfulness.[57] Six apps designed for people experiencing breathlessness with a variety of health conditions were assessed for their usability and compliance to industry standards related to data usage, confidentiality and security, using the MARS and Health on the Net (HON) Code, respectively.[29] Most of the apps were available on the Android platform, and have features to support education (3/6), exercise recommendations (3/6), and less commonly, medication reminders (1/6), symptoms tracking (1/6), and referrals to healthcare providers (2/6).[29] The authors reported fair usability, but apps were likely to lack the ability to support behavioural changes to decrease people's breathlessness, and none of the apps were completely compliant with the HON code.[29] Similarly, in the study by Owens et al, nine public apps (searched May 2017) designed for promoting mindfulness strategies in people living with chronic lung diseases were poor, with app content not in alignment with scientific evidence.[57] Neither apps reviewed by Owens et al and Sunjaya et al were exclusive to COPD self-management, but both demonstrate the poor quality, limited usability and overall lack of details toward privacy and security in public apps.[29,57] These findings are similar to our results, where public apps are lacking in high quality,[29,44,45,57] but our study was unique for assessing mHealth apps targeted towards complete COPD self-management and reviewed qualities beyond their features and basic security characteristics, using one framework.

There is one study that has evaluated apps using the MIND framework; the authors evaluated diagnostic and screening apps for perinatal mental health.[39] Most apps were developed by for-profit companies (10/14), with only half of them accessible on both mobile platforms, and the common feature was education (6/14) and only one app referenced a peer-reviewed study.[39] In regards to privacy and security characteristics, 11 of 14 apps had privacy policies with an average FKGL 12.3 and two apps claimed to be compliant with HIPAA.[39] Between our studies, there is the need for current mHealth apps to be assessed for their clinical effectiveness and improved data protection and sharing,[39] irrespective of their intended user population. In contrast to other usability and quality assessment scales mentioned above,[29,44,45] the MIND incorporates all of these elements into one large framework, demonstrating its comprehensiveness in multiple domains.[35] The broad applicability of the MIND framework in our study and Spadaro et al.[39] demonstrate its valuable information in guiding the development and improvement of future mHealth apps in mental health and COPD self-management.

Despite our search for apps relevant to COPD self-management, many irrelevant apps to COPD management were found. This could be due to using multiple key terms to search the app marketplaces for thoroughness and the possibility of apps using COPD-related terms as key words in their descriptions. It is unclear whether this strategy was used to promote their apps' visibility,[58,59] but it did increase the risk of confusion for misinformation. We also noted more apps on Google Play store than on the Apple store, possibly due to the differences in the terms required by these organizations for developers to release their apps onto their platforms and to promote their products.[60]

With the app marketplace rapidly evolving,[56] three of the originally included apps became unavailable over the duration of this study. This fluidity makes it difficult for potential

users to be up to date on the number and content of public apps.[56] This dynamic change in apps availability has been addressed in mental health self-management by the creation of a public database of evaluated apps. Harvard Medical School in partnership with Beth Israel Deaconess Medical Center host the online MIND database, where clinicians and users can find the most appropriate mental health apps, previously validated by MIND assessments completed by trained raters.[32,35] Similarly, public COPD apps also evolve and change over time, necessitating a feasible solution to ensure and maintain their credibility and qualities.[44,57]

This study showed the inadequate state of the quality of public COPD apps' and their use for self-management. As many of the public apps assessed in this study did not provide these features mentioned in the literature or outlined in the MIND framework, COPD app developers need to be conscientious of incorporating the support needs of people with COPD, so features and resources are aligned with patients' needs for better self-care.[3,7,48] Areas of app improvement include the need for referencing credible information,[31,34] providing consistent and relevant updates in parallel with the emerging evidence,[46,47] improved privacy and security for data protection,[56] and the ability to share data with relevant clinicians.[9,18,22] There should be considerations to include the need for reading level appropriate content, goal personalization, peer networking and self-monitoring to enforce positive behaviours.[30,48,57] Apps should also allow for content customization to meet individual users' needs, and enable users' family or caregivers to be involved with the app.[47] The MIND framework outlined many possible features and engagement styles for apps to interact with their users, serving as a guide for developers to incorporate potential features that will encourage patient engagement with their healthcare providers, and provide personalized feedback in the forms of alerts, reminders, education or coaching to facilitate behavioural changes for improved disease control.[30,46] Additionally, apps

need to be user-friendly for successful implementation.[26] Furthermore, collaborations between COPD app developers, researchers and healthcare systems are necessary to ensure the safe integration of features, content and adoption into healthcare plans.[46] Public COPD apps are readily accessible and show promise in facilitating COPD self-management; however, strategic plans and regulations are required to ensure their credibility and safe integration.[34]

3.62 STRENGTHS AND LIMITATIONS

Study strengths included minimizing bias by two reviewers independently screening and assessing all apps before discussing their findings, minimizing bias. There is significant variability in quality assessments for mHealth apps, and emphasizing the need for evaluations to address clinical impact and behavioural change mechanisms.[34] As the MIND framework is derived from 45 frameworks focused on general and specific disease domains including asthma, heart failure, mental health and pain management,[32] many aspects of the apps' characteristics and features were reported.[32] This comprehensive assessment would not have been possible with other frameworks, as they commonly reviewed the effectiveness of apps and their features, often missing other important design elements such as privacy and security characteristics.[44,61] Lastly, the MIND framework was originally developed to assess public apps for mental health.[35] However, we decided to apply this comprehensive framework onto another category of mHealth apps, those for meant for COPD self-management. To our understanding, this is the first time the MIND framework was applied in this context.

Limitations are only including mHealth apps in English that were free to download, as cost can be an accessibility barrier.[26,37,45] It may be possible for paid apps to be of higher quality with features that would have meaningful impact on users' self-management. Additionally, we were unable to evaluate several apps in the Apple or Google Play stores as they were restricted to

study participants enrolled in ongoing clinical studies.[23,51,55] Lastly, app stores are not designed for research based structured searches,[62] it is challenging for searches to be updated and replicated for future studies.[39] We noticed that search results were inconsistent, where the order of apps appeared differently despite using the exact keywords. This is likely due to regional restrictions, and search algorithms driven for promotion and commercial profit in certain geographical locations, influencing the retrieved app results.[59,62] Instead of displaying the total number of apps for each search term, both Apple's and Google's app stores required the reviewers to blindly scroll through the results list until it stopped loading, indicating all apps for a specific keyword were shown. Being unable to see the total for each keyword made it challenging for reviewers to revisit the search at another time, a common challenge reported in another scoping review.[39]

3.7 CONCLUSIONS

COPD apps in the public marketplace have inadequate qualities and features to address privacy concerns and insufficient information to demonstrate their credibility or effectiveness for self-management. Publicly available COPD apps should be used with caution as many have the potential to cause harm to their users.

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CHAPTER 4: STAKEHOLDERS' OPINIONS ON COPD MHEATH APPS

Public Mobile Chronic Obstructive Pulmonary Disease Applications for self-management: Patients and Healthcare Professionals' Perspectives

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Public Mobile Chronic Obstructive Pulmonary Disease Applications for self-management: Patients and Healthcare Professionals' Perspectives

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4.1 ABSTRACT

Poorly controlled chronic obstructive pulmonary disease (COPD) can negatively impact quality of life but mobile applications (apps) are popular digital tools that may mitigate these support needs. However, it is unclear if public COPD apps are acceptable to healthcare professionals and individuals living with COPD. The objective of this study was to determine the perspectives of healthcare professionals and patients' lived experience on the appropriateness of public COPD apps for supporting individuals' needs using the RAND/UCLA Appropriateness Method. Public apps were rated by questionnaires administered before and after focus group meetings. Ratings were reported as medians with interquartile ranges and median scores were categorized into three levels of appropriateness: 1-3 for inappropriate; 4-6 for uncertain; and 7-9 for appropriate. A total of 6 patient participants (mean age 68.2±4.8y) and 22 healthcare professionals (mean age 45±8.3y) completed this study. Patient participants identified one and healthcare professionals identified three public COPD apps to be appropriate. Stakeholders mutually rated one public COPD app as appropriate for self-management but had different preferences for features and engagement styles. Stakeholders identified similar facilitators and barriers to app use and emphasized the need for apps to be supplementary and customizable, rather than replacements for clinical management.

Keywords: COPD; digital health; mobile technology; respiratory care; respiratory health

4.2 INTRODUCTION

The prevalence of chronic obstructive pulmonary disease (COPD) in Canadians steadily increases with age, from an estimated 0.8% in 35 to 40 year old to 8.3% in those over 65 years old, totalling to about 2 million people.[1,2] COPD care is a significant burden to the healthcare system, with an estimated cost of approximately $1.5 billion Canadian dollars (CAD) in 2017,[3] and will likely increase to cost $101.4 billion CAD by 2035.[4] Many patients with COPD experience physical and mental health burdens to their lives, especially when their pulmonary and extra-pulmonary symptoms are left uncontrolled.[5-7] Therefore, to minimize the personal and economic burden of COPD, it is necessary to strengthen the efficacy and uptake of current and novel approaches for disease management.[4,6,8]

COPD self-management has been shown to improve symptoms[9] and health related quality of life,[9,10] as well as to reduce hospitalizations.[11,12] Self-management should be carefully tailored to patients' needs, incorporating elements of disease knowledge, behavioural changes and emotional support to optimize self-efficacy.[8,13] Use of technologies such as mobile applications (apps) have potential as useful tools to improve access to resources and to facilitate self-management.[14] There are several studies evaluating the effectiveness of mobile COPD apps in patient outcomes, including decreased symptom severity,[15] hospital readmissions,[16,17] smoking behaviours,[18] and increased physical activity.[12,18-20] Although mobile apps are often easy to use, there is limited information regarding their effectiveness.[14,15,21]

In 2018, Statistics Canada reported 88% of Canadians owned a smartphone,[22] and the Canadian Agency for Drugs and Technology in Health (CADTH) suggested smartphone availability enforced people's interest in using readily available health apps for their chronic diseases.[23] In combination with the recent pandemic, interest for using apps for health self-management have grown, demonstrating the need for awareness between patients and healthcare

professionals. Using mobile apps may have benefits,[14,21] but common barriers to their uptake include financial limitations and privacy and confidentiality concerns.[24-27] Past studies have evaluated apps created by research teams, [28] but these are inaccessible to the public. Therefore, greater attention towards public COPD apps is necessary since they are easily accessible to people and can be used without supervision.[29,30] There are many free COPD self-management apps in the current marketplace, although their credibility is unclear. This lack of regulation and monitoring of health information generates concerns for their safe use, prompting researchers at Harvard Medical School, Division of Digital Psychiatry, to create and implement the mHealth Index and Navigation Database (MIND; https://mindapps.org/).[31,32] The MIND Framework was created with the primary goal of displaying the assessments of public mental health apps with over 100 objective questions, across five domains. Currently, MIND serves as a repository of app assessments for publicly accessible mental health apps to ensure healthcare professionals, patients and target-users have the necessary information to make informed choices on their use. Previously, we used the MIND Framework to evaluate free COPD self-management apps in the public marketplace and found they were mostly created by for-profit organizations, with variable features, questionable credibility, and no evidence to support clinical use.[29] Given their poor designs and credibility concerns based on standardized checklists, it is important to further understand how these apps are perceived by their targeted stakeholders and users.

The objectives of this study were to explore the perceptions of healthcare professionals and persons living with COPD regarding: 1) the appropriateness of public COPD self-management apps available in the marketplace; 2) the ideal app qualities (features, input and output data) for COPD self-management, and 3) the facilitators, barriers and needs for app use, from the perspective of healthcare professionals and patients living with COPD.

4.3 MATERIALS AND METHODS

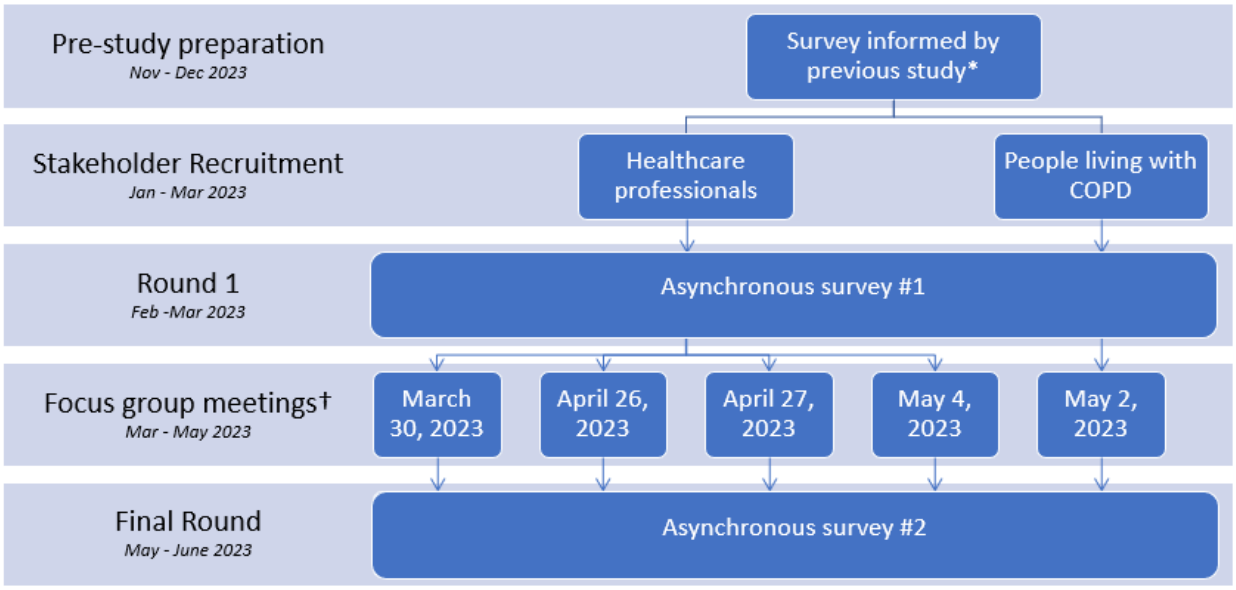
4.31 STUDY DESIGN:

Healthcare professionals and people with COPD were invited to participate in a prospective, virtual RAND/UCLA Appropriateness Method study to share their perspectives and feedback on the appropriateness of public COPD self-management apps and their ideal characteristics.[29] This study was approved by the McMaster University Research Ethics Board (Project# 15484). Written and/ or verbal consent from each participant was obtained prior to study enrolment.

4.32 RAND/UCLA APPROPRIATENESS METHOD (RAM):

The RAM is a variant of the Delphi consensus technique, and the detailed process of conducting the RAM is described in the manual published by the RAND Corporation in 2001.[33] This method utilizes collective feedback from experts and existing evidence to form a consensus opinion about a particular topic.[34,35] Individuals qualified to be experts in a RAM study are identified by the research team, as individuals are with adequate knowledge and experience in the topic of interest.[33] The overall purpose of the RAM is to discuss the appropriateness of the ideas presented, not to generate new ideas.[33,34] The experts provide their feedback across two rounds using two questionnaires and one focus group meeting in between.[33,35] Round 1 consists of experts completing a questionnaire anonymously and asynchronously. Round 1 data is aggregated and provided to the experts to review prior to round 2, which includes the focus group meeting and the final questionnaire. See Figure 1 for an overview of the process in this study.

Figure 3 Timeline and flow diagram of the RAND/UCLA method used for this study.



*Contents of the survey were informed by research team's previous work[29] and list of possible features, and engagement styles outlined in the MIND framework[31,32]; †Focus group meetings were approximately 60 to 90 minutes in length. See supplementary materials for survey and moderator guide.

4.33 PARTICIPANTS AND RECRUITMENT:

The stakeholder groups for this study were: 1) people living with COPD; and 2) healthcare professionals with experience caring for people with COPD. Patient participants were eligible if they were diagnosed with COPD as defined by the GOLD criteria. Healthcare professionals were eligible to enrol if they had experience treating and caring for patients with COPD, and were from a regulated healthcare discipline, including, but not limited to physiotherapists, occupational therapists, respiratory therapists, respirologists, and nurses. All participants were required to have interest in the use and potential of mobile technology in healthcare. They were also required to be proficient in English to provide informed consent and feedback.

Healthcare professionals were identified by public websites (i.e., university profiles, clinic staff directory) and by the snowball sampling technique. For patient participants, we used a registry of individuals who had agreed to be contacted regarding participating in clinical research. All potential participants were invited by e-mail, with reminder emails sent two weeks after the initial email if a response was not received. After this timeframe, no further emails were sent.

4.34 QUESTIONNAIRE DEVELOPMENT:

The questionnaire consisted of a list of public COPD apps generated from our previous evaluation report, where qualities of public COPD apps were critically assessed.[29] These apps were COPD specific, patient-facing, free from the Apple and Google Play Store, but only 10 of the 13 public apps were still available to be included in this questionnaire. Participants were not expected to download the apps as the research team created an infographic handout outlining each app's characteristics, features and other qualities for them to review before providing their feedback. The infographic handout is available in supplementary material.

For ideal app qualities, they were derived from the available list on the MIND Evaluation framework.[32] This questionnaire was specifically seeking participants' feedback on features and qualities related to the user experience, thus only items listed under the Engagement style domain of the MIND evaluation framework were included.[32] See supplementary material for the questionnaire.

4.35 STUDY PROCESS:

Participants were electronically invited to provide their opinion on the appropriateness for each item on the survey using a 9-point Likert scale, where 1 to 3 for inappropriate, 3 to 6 for uncertain, and 7 to 9 for appropriate (Table 1) . Research Data Capture (REDCap)[36] was used to distribute and manage data collection for the questionnaires in round 1 and 2.

Table 13: Classification of the level of appropriateness and agreement based on each item's aggregated median and rankings. Information adapted from RAND/UCLA Appropriateness User Manual.[33]

Median	**≥75% Participants**	**Classification**
1 – 3	No	Inappropriate without agreement
1 – 3	Yes	Inappropriate with agreement
4 – 6	No	Uncertain without agreement
4 – 6	Yes	Uncertain with agreement
7 – 9	No	Appropriate without agreement
7 – 9	Yes	Appropriate with agreement

After round 1, the responses were summarized and analyzed to provide participants with a summary of the median and individual rating for each questionnaire item. This handout was provided to participants prior to their focus group meeting (the handout template is available in supplementary material).

Next, the focus group meetings were conducted and recorded on Zoom (license provided by McMaster University), scheduled for approximately 60 minutes, facilitated by SQ using an

ethics approved moderator guide. Patient participants and healthcare providers were scheduled into separate peer focus group meetings to reduce influence or discomfort individuals may experience when sharing their personal thoughts.[37]

4.36 DATA ANALYSIS:

Demographic information and responses to the questionnaires were aggregated to report the means, medians, dispersion ranges (standard deviations, interquartile ranges), frequencies and percentages, where appropriate. The median for each questionnaire item was used to classify the level of appropriateness, categorized by 3-point tertile: 1 to 3 for inappropriate; 4 to 6 for uncertain; and 7 to 9 for appropriate.[33,34] Participants reached an agreement for the appropriateness of the item if at least 75% of the participants' responses were in the same appropriateness category, see Table 1.[33]

Audio files were transcribed verbatim and stripped of identifiers by a third party transcriber. Transcription analysis was completed using Microsoft Excel by two independent authors (SQ, AB) using deductive analysis. A code manual was developed using the questionnaire categories as general categories (I.e., public COPD apps, features, inputs, outputs) and those identified in previously reported mixed methods studies by Alwashmi et al.[26,38] The reliability of the codes were tested on one transcript before the reviewers compared results and mutually agreed on the modifications to the predetermined code manual. The qualitative data were organized by categories; participants' quotes were used to illustrate and supplement the questionnaire results and the discussion of apps in clinical care.

4.4 RESULTS

4.41 PARTICIPANTS' CHARACTERISTICS:

Email invitations were sent to six patients with COPD across Ontario and Manitoba and 43 healthcare professionals across seven provinces in Canada, leading to expressed interest from all six (100%) patients and 25 (58%) healthcare professionals. A total of 28 participants participated, six (21%) patients with COPD and 22 (79%) healthcare professionals.

The mean age (±standard deviation [SD]) of patients was 68.2 (4.8) years with four females (67%). All patients were diagnosed with COPD over 5 years ago and have experienced acute exacerbations of COPD within the last year. Regarding their interest in mobile apps for self-care, three (50%) felt that apps have the potential to facilitate their self-management needs, while one (17%) said no, and two (33%) were unsure. Full characteristic details of the enrolled patients are outlined in Table 2.

The mean age (SD) of healthcare professionals was 45 (8.19) years with 15 (62%) female participants. Healthcare professionals included were from multiple professions, including physicians (5, 23%), physiotherapists (5, 23%), nurses (5, 23%), respiratory therapists (5, 23%), a pharmacist (1, 5%) and an occupational therapist (1, 5%). They had at least one year of experience treating patients with COPD, with four (18%) having over 20 years of experience. All healthcare professionals worked in an urban areas, with the majority practicing at rehabilitation centers (12, 55%), acute care hospitals (4, 18%), primary care clinics (5, 23%), speciality clinics (2, 9%), and post-secondary institutions (2, 9%). Regarding their interest in mobile apps to support patients' self-management, 19 (86%) felt that mobile apps could be integrated into patient-care plans and 20 (91%) would recommend them if they were credible and validated. All healthcare professionals believed that mobile apps had the potential to support patients with their

COPD self-management. Full characteristic details of the healthcare professionals are outlined in Table 3.

Table 14: Demographic characteristics of people living with COPD.

Measure	Item	Count (%)
Sex	Female	4 (67)
Age	Average (SD)	68.17 (4.83)
	Median (Q1, Q3)	67 (65, 69)
City of residence	Semi-urban centre (1000-5000 habitants)	2 (33)
	Urban centre (>5000 habitants)	4 (67)
Time of COPD diagnosis	6-10 years ago	2 (33)
	11-15 years ago	2 (33)
	Over 15 years ago	2 (33)
Last COPD exacerbation	3-6 months	1 (17)
	7-9 months	3 (50)
	9-12 months	2 (33)
Last hospitalization for COPD exacerbation within the past year	None	3 (50)
	1 time	2 (33)
	2 times	1 (17)
mMRC Dyspnea	0	0
	1	1 (17)
	2	4 (67)
	3	1 (17)
	4	0
Requires help	Yes	2 (33)*
Interest in apps in self-care		
Do you think mobile applications have potential to help you with your self-management?	Yes	3 (50)
	No	1 (17)
	Unsure	2(33)

*patients require help with housework and transportation

Table 15: Demographic characteristics of healthcare professionals.

Measure	Item	Count (%)
Sex	Male	8 (36)
	Female	14 (64)
Age	Average	45 (8.27)
	Median	46 (41, 51)
Health Care Role	Respirologist	4 (18)
	Family physician	1 (5)
	Physiotherapist	5 (23)
	Registered Nurse	4 (18)
	Nurse practitioner	1 (5)
	Respiratory Therapist	5 (23)
	Pharmacist	1 (5)
	Occupational Therapist	1 (5)
Years spent providing care for people with COPD	1-5 years	3 (14)
	5-10 years	6 (27)
	10-20 years	9 (41)
	20 or more years	4 (18)
Work setting†	Acute care hospital	4 (18)
	Primary care	5 (23)
	Specialty clinic	2 (9)
	Rehabilitation center	12 (55)
	Post-secondary institution	2 (9)
Interest in apps to support patients		
Do you think mobile applications can be integrated into patients' care plans?	Yes	19 (86)
	Unsure	3 (14)
Do you think mobile applications have potential to help patients with their self-management?	Yes	24 (100)
Would you recommend mobile applications (if validated, and credible) for your patients?	Yes	20 (91)
	Unsure	2 (9)

*Includes nurse practitioner and family physician; †several participants worked in more than one clinical setting.

4.42 QUESTIONNAIRE RESPONSES – PUBLIC COPD APPS:

Of the ten public COPD apps, patient stakeholders were uncertain about all apps' appropriateness in COPD self-management in round 1 (Table 4). After the focus group meeting, one app was ranked appropriate (the COPD Pocket Consultant Guide created by the COPD Foundation (https://www.copdfoundation.org/Learn-More/The-COPD-Pocket-Consultant-Guide/Healthcare-Provider-Track.aspx)). In contrast, healthcare professionals ranked three apps as appropriate in the questionnaire before and after the focus group meeting (COPD Support, COPD Pocket Consultant Guide, NHS Wales: COPDHub) (Table 5). The remaining apps were rated as uncertain. After the focus group meetings, the same three apps identified from round 1 were re-rated as appropriate, with one app rated as inappropriate. Across both questionnaires, healthcare professionals rated the COPD Pocket Consultant Guide as appropriate, with agreement. See Tables 4 and 5 for details on the ratings for each public COPD apps surveyed.

Table 16: Cumulative ratings of public COPD apps by people living with COPD, before and after focus group meeting.

	Pre-Meeting (T1)			**Post-Meeting Survey (T2)**		
Public Apps	Inappropriate	Uncertain	Appropriate	Inappropriate	Uncertain	Appropriate
COPD Support		✓			✓	
Home Remedies for COPD		✓			✓	
COPD		✓			✓	
Chronic Obstructive Pulmonary Disease Assessment		✓			✓	
Book of COPD		✓			✓	
NIH: COPD		✓			✓*	
Chronic Lung Disease Treatment		✓			✓	
COPD Pocket Consultant Guide		✓				✓
NHS Wales: COPDhub		✓			✓	
Pulmonary Scan		✓			✓	

* = Agreed when ≥75% of participants' ranks fell within a category, i.e., inappropriate (1-3), uncertain (4-6), appropriate (7-9)

Table 17: Cumulative ratings of public COPD apps by healthcare professionals, before and after focus group meeting.

	Pre-Meeting (T1)			**Post-Meeting Survey (T2)**		
Public Apps	Inappropriate	Uncertain	Appropriate	Inappropriate	Uncertain	Appropriate
COPD Support			✓			✓
Home Remedies for COPD		✓		✓		
COPD		✓			✓	
Chronic Obstructive Pulmonary Disease Assessment		✓			✓	
Book of COPD		✓			✓	
NIH: COPD		✓			✓*	
Chronic Lung Disease Treatment		✓			✓	
COPD Pocket Consultant Guide			✓*			✓*
NHS Wales: COPDhub			✓			✓
Pulmonary Scan		✓			✓	

* = Agreed when ≥75% of participants' ranks fell within a category, i.e., inappropriate (1-3), uncertain (4-6), appropriate (7-9)

4.43 QUESTIONNAIRE RESPONSES – FEATURES AND ENGAGEMENT STYLE:

Patient stakeholders rated 11 of 18 (61%) app features as appropriate with 3 (17%) meeting the 75% threshold for agreement in round 1, but after the discussion, they only rated six (33%) to be appropriate. The six features that rated appropriate for before and after the meeting were: 1) medication tracking; 2) physical exercise tracking; 3) deep breathing exercises; 4) peer support; 5) connection to therapist/ coach; and 6) physical health exercises. Patient participant rated inputting contacts, step counts and external devices (3/9, 33%) to be appropriate app engagement styles in round 1, but were collectively uncertain after the focus group meeting. As for output styles, patient participants regarded both reminders and connections to formal care as appropriate (2/6, 33%) but their final ratings only identified connections to formal care to be appropriate. See Table 6 for details.

Healthcare professionals rated many features to be appropriate before and after their focus group meetings. Pre-focus group meeting, 16 (89%) appropriate with 10 (56%) reaching the 75% threshold of agreement. However, after discussion, 13 (72%) were rated appropriate with only 4 (22%) reaching consensus agreement. The four features rated appropriate with agreement amongst healthcare professionals were: 1) medication tracking; 2) physical exercise tracking; 3) mindfulness exercises; and 4) peer support. Other features that were rated appropriate at both time points but failed to achieve agreement were: 1) mood tracking; 2) sleep tracking; 3) psychoeducation; 4) deep breathing; 5) sleep therapy; 6) connection with therapist/ coach; 7) biodata; 8) goal setting; and 8) physical health exercises. For input styles, healthcare professionals rated four (44%) data inputs as appropriate in round 1 but this changed to only three (33%) after the meeting, specifically: 1) surveys; 2) step counts; and 3) external devices. Only input for step counts was rated appropriate and reached the threshold for agreement. For output styles, healthcare professionals rated five (83%) data outputs as appropriate at both

timepoints: 1) notifications; 2) reminders; 3) data graphs; 4) data summaries; and 5) connections to formal care. Only notifications and reminders were rated as appropriate with at least 75% agreement at both timepoints. See Table 7 for details.

Table 18: People living with COPD - Cumulative ratings of potential features, output, and input engagement styles to consider in COPD self-management

	Pre-Meeting (T1)			**Post-Meeting (T2)**		
Features	Inappropriate	Uncertain	Appropriate	Inappropriate	Uncertain	Appropriate
Mood Tracking			✓		✓	
Medication Tracking			✓			✓
Sleep Tracking		✓		✓		
Physical Exercise Tracking			✓			✓
Psychoeducation			✓		✓	
Journaling		✓			✓	
Picture Gallery/ Hope Board		✓			✓	
Mindfulness Exercises			✓*		✓	
Deep Breathing			✓*			✓
Sleep Therapy/ Interventional Cognitive Therapy			✓		✓	
Psychotherapies [a]		✓			✓	
Peer Support			✓			✓
Connect with coach/ therapist			✓			✓
Biodata			✓*		✓*	
Goal Setting/Habits		✓			✓	
Physical Health Exercises			✓			✓
Bbot [b]		✓			✓	
Biofeedback		✓			✓	
Engagement style						
Input	Inappropriate	Uncertain	Appropriate	Inappropriate	Uncertain	Appropriate
Surveys		✓			✓	
Diary		✓			✓	
Geolocation		✓			✓	
Contact list			✓		✓	
Camera in the App		✓			✓	
Microphone in the App		✓			✓	
Step Count			✓		✓	

External Devices			✓*		✓	
Connect Social Media		✓			✓	
Output	Inappropriate	Uncertain	Appropriate	Inappropriate	Uncertain	Appropriate
Notifications		✓			✓	
Social Network		✓			✓	
Reminders			✓		✓	
Data Graphs		✓			✓	
Data Summary		✓			✓	
Links to Formal Care/Coaching			✓			✓

* = Agreed when ≥75% of participants' ranks fell within a category, i.e., inappropriate (1-3), uncertain (4-6), appropriate (7-9); [a] Behavioural therapy that includes cognitive, acceptance and commitment, and dialectical behavioural therapy; [b] interactive virtual character, i.e., users can interact with virtual robot

Table 19: Healthcare professionals - Cumulative ratings of potential features, output, and input engagement styles to consider in COPD self-management apps.

	Pre-Meeting (T1)			**Post-Meeting (T2)**		
Features	Inappropriate	Uncertain	Appropriate	Inappropriate	Uncertain	Appropriate
Mood Tracking			✓			✓
Medication Tracking			✓*			✓*
Sleep Tracking			✓*			✓
Physical Exercise Tracking			✓*			✓*
Psychoeducation			✓*			✓
Journaling			✓		✓	
Picture Gallery/ Hope Board		✓			✓	
Mindfulness Exercises			✓*			✓*
Deep Breathing			✓*			✓
Sleep Therapy			✓			✓
Psychotherapies [a]			✓		✓	
Peer Support			✓*			✓*
Connect with a coach/ therapist			✓*			✓
Biodata			✓			✓
Goal Setting/Habits			✓*			✓
Physical Health Exercises			✓*			✓
Bbot [b]		✓			✓	
Biofeedback			✓		✓	
Engagement style						
Input	Inappropriate	Uncertain	Appropriate	Inappropriate	Uncertain	Appropriate
Surveys			✓*			✓
Diary			✓		✓	
Geolocation		✓			✓	
Contact list		✓			✓	
Camera in the App		✓			✓	
Microphone in the App		✓			✓	
Step Count			✓*			✓*
External Devices			✓*			✓

Connect Social Media		✓			✓	
Output	Inappropriate	Uncertain	Appropriate	Inappropriate	Uncertain	Appropriate
Notifications			✓*			✓*
Social Network		✓			✓	
Reminders			✓*			✓*
Data Graphs			✓*			✓
Data Summary			✓			✓*
Links to Formal Care/Coaching			✓*			✓

* = Agreed when ≥75% of participants' ranks fell within a category, i.e., inappropriate (1-3), uncertain (4-6), appropriate (7-9); [a] Behavioural therapy that includes cognitive, acceptance and commitment, and dialectical behavioural therapy; [b] interactive virtual character, i.e., users can interact with virtual robot.

4.44 FOCUS GROUPS:

Between the two rounds of questionnaires, participants were invited to engage in peer discussions about the public COPD apps, app features and qualities outlined in the questionnaire, at the scheduled meetings held from March to May 2023. All patient participants attended their focus group meeting on May 2, 2023. For healthcare professionals, a total of four focus group meetings were assembled to maximize participation and disciplines were distributed across each meeting to ensure diversity of the participants. A total of 21 (95%) healthcare professionals attended their assigned focus group meeting. See Figure 1 for the timeline.

Five overarching categories were used to analyze the transcripts for both stakeholders: 1) appropriateness of public COPD apps; 2) ideal features and qualities; 3) facilitators to app use; 4) barriers to app use; and 5) needs for apps for self-management. These categories were further classified into subcategories, with a few concepts recurring across categories and stakeholder groups. These categories and subcategories are outlined in Table 8 for patients, and 9 for healthcare professionals).

1. Appropriateness of Public COPD apps

Generally, both stakeholder groups noted most public COPD apps to be questionable and inappropriate. However, both stakeholder groups expressed the COPD Pocket Consultant Guide app by the COPD Foundation was the most appropriate for patients' use based on its comprehensiveness and credibility.

2. Ideal Features

Education and connection with peers experiencing the same disease were regarded as important features by patients. Additionally, features to connect everyone on their healthcare team together was viewed as optimal. In contrast, healthcare professionals strongly emphasized

ideal features to be more than informational, requiring features to be interactive and motivational to engage with their users and to be clinically meaningful.

3. Facilitators to app use

Regarding the use of apps for their COPD self-management, patient stakeholders noted that apps need to be vetted by their healthcare team and must be customizable to address individuals' differing needs. Healthcare professionals discussed and identified many potential facilitators that could support patients' use of apps such as app credibility, interactive features, and overall ease of use. Furthermore, healthcare professionals discussed the potential of apps as adjunct support tools to their own practices. All of these were listed as important considerations to facilitate app use in patients, but also to facilitate healthcare professionals' willingness to adopt apps in their clinical practice.

4. Barriers to app use

Amongst the patient stakeholders, privacy concerns and feelings of being overwhelmed prevented them from using apps. Particularly, patients described apps with features seeking information through questionnaires with constant reminders caused them to feel stressed and burdened, leading to an unwillingness to use apps. Similarly, healthcare professionals expressed privacy and safety concerns to be barriers in app use. Safety concerns included the possibility of apps providing unverified advice, the developers' level of credibility and the need for evidence to support their use.

5. Needs for future apps

A gap identified by patient participants was the lack of consultation with people living with COPD in the design of these public COPD apps. Patient stakeholders also emphasized the

need for future apps to integrate app features facilitating communication between the members of their health team and ensuring they are informed of their action plans.

Meanwhile, the needs identified by healthcare professionals included focus on mental health and wellbeing, customization to address personalized needs and the liability associated with app use. If apps were to be adopted and integrated into care plans, professional liability and oversight are required to ensure their safe use. Healthcare professionals stressed the need for frequent and ongoing evaluations of emerging COPD self-management apps to understand their potential in clinical practice. The healthcare professionals acknowledged that their needs and desires in apps likely diverged from those of patients.

Table 20: Identified themes and subthemes in patients' focus group meeting (May 2, 2023) and corresponding quotes.

	Quotes
Public COPD apps	
Appropriate: COPD Foundation	*"I did find one that I liked. COPD Foundation. It was a very comprehensive app and had lots of links*."
Inappropriate: -Difficult to comprehend -Lack of support	*"I want to be able to read treatments and diagnoses and so on and not answer all these questionnaires and not get anything back. A lot of the questionnaires were really complicated, and it would be very hard for a lay person to answer*."
Ideal features	
Education	*"I found education was the cornerstone of my recovery. The exercise was a great thing but hearing little tidbits of this, that, and the other thing that you can apply to your everyday life."*
Peer support	
Connection to healthcare team	*"The key is to have everyone connected. Your family doctor, your respirologist, your pharmacist. Everybody must be connected."*
Facilitators	
Credibility	*"I don't think any of the apps were very comprehensive or written by or in consultation with a COPD patient."*
Team support	*"The key is to have everyone connected. Your family doctor, your respirologist, your pharmacist. Everybody has to be connected."*
Customization	*"You cannot paint COPD with the same brush. Everyone has a different story and is coming from a different direction."*
Barriers	
Privacy concerns	*"I found that they were asking for a lot of information, and I did not want to give out that information."*
Overwhelmingness	*"They wanted you to keep track of your daily scores, tracking symptoms so on and so forth and just all the questionnaires right off the bat, it turned me right off."*
Needs	
Team support	*"I would want it coming from doctors, respirologists and physiotherapists and people who play a big part in COPD. That would draw me in."*
Consultation with patient-users	*"I don't think any of these apps were designed by a COPD patient."*

Table 21: Focus group meetings for healthcare professionals occurred across four meetings dates. Identified themes and subthemes below were consistently mentioned in all meetings, and sample quotes are provided.

	Quotes
Public COPD apps	
Appropriate: COPD Foundation	*"When you compare all the apps and look at what the COPD Foundation app offered, the other ones fail in comparison…"* "*I think the COPD Foundation are reputable and that would seem like the best fit."*
Inappropriate: -Non-interactive -Questionable credibility -Home remedies for COPD	*"I cannot imagine people going back to that app to look up information when they can go to a website. It seemed like a single use kind of thing as opposed to an app."*
Ideal features	
Interactive components	*"I liked the app about how you are feeling on the daily, tracking emotions that would explain why you are having a higher breathing day. I liked the more detailed ones or the goal setting apps.*"
Motivational components	*"If they had something to motivate them to keep going in that regard and P2 mentioned having awards or prizes and making it competitive or at least rewarding, because a lot of patients that I am seeing, once the exercise is done, that's it and as they would say, go back and sit on their butts and do nothing."*
Peer support	"*I find also that peer support is really important. I know personally that is one of the ways that I keep myself motivated or to do things like that."*
Facilitators	
Credibility	*"I like the idea that the apps are funded or founded by institutions that appear legitimate and as an evidence-based practitioner and as P2 was saying, I had not put these into use and thoroughly evaluated them."*
Interactive	*"Anything that really involved the patient in terms of their experience and how they were feeling, their moods and those types of things. Those intangible things that we do not think about really sticks out."*
Ease of use	*"Not overwhelming the patient with a lot of information which for them would not engage them in their care."*
Integrated use	*"Maybe that needs to be our focus, on how best to integrate them but not how to use them as a stand alone…* "

Health benefits	"W*e don't have enough time to educate the patients about the disease and the medications and maybe the apps can add this part*."
Barriers	
Privacy concerns	*"You never know what is going to happen with that data. If you could have a closed loop where your phone or your app is connecting to your healthcare provider, your clinic or day hospital no problem but if it is a third party type of a Peloton thing then I do not like that idea."*
Safety concerns	*"A lot of the resources seemed really questionable and just going through these apps and really wondering the basis and the references for these."*
Limited uptake by elderly	*"Our patient population, a lot of them are older as well and they are not as familiar with using apps and it might not be the most friendly thing for them*."
Needs	
Customization	*"The thing that matter to me as a clinician are not the same things that matter to patients. So build their own app from a menu of options and tailor it towards what they want to have."*
Mental health needs	*"I am finding that 99.9% of them are dealing with anxiety and it's almost out of control. So, I guess I would like to see a little bit focus on the mental health."*
Liability	*"If such apps are to be implemented, it should be through a health team where there is some liability for both sides."* *"There has to be professional oversight to a lot of this and that is the important thing."*
App growth and research	*"…sometimes we do not give enough credit to our older folks and what they are willing to figure out in order to stay connected with the world as it is."* *"In the next 10-20 years, everyone who is going to potentially have COPD will be very tech savvy … It seems like this would be an appropriate thing to consider and very meaningful to me as a healthcare provider."*

4.5 DISCUSSION

In this study, we used questionnaires and focus groups to ascertain the opinions of people with COPD and healthcare professionals on the appropriateness of public COPD apps in supporting self-management, the ideal features required to support people living with COPD, the facilitators and barriers for use and the ongoing needs for future COPD app development. The COPD Pocket Consultant was considered by both groups to be the most appropriate app. The remaining public COPD apps were ranked with uncertainty and inconsistent endorsement between the two stakeholder groups. Ideal features differed among the stakeholders but there were shared endorsements of their value for peer support, medication tracking and physical exercises.

COPD Pocket Consultant by the COPD Foundation was consistently rated as appropriate by both stakeholders, which may be attributed to what the app offers to patients. The patient's version provides patients and their caregivers with multiple features to support COPD self-management, incorporating elements of symptom tracking, medication tracking, physical exercises education and tracking, COPD action plan, COPD360Social (peer support network), patients' blog and appointment reminders. Many of these features align with previous reports.[8,38,39] Interest and high appropriateness rankings between the stakeholder groups could be due to the app's origin and credibility from a reputable non-profit organization, partnered with health professionals, in North America (https://www.copdfoundation.org/). Our previous report found this app to be one of the more comprehensive apps available as rated using the MIND Framework.[29]

NHSWales: COPDHub was ranked as appropriate by healthcare professionals, likely because it was developed by the Welsh National Health Service as part of digital solutions to support clinicians to improve patient care (https://www.nhs.wales/). Although COPDHub has

elements of personalized COPD plans, education and clinical data tracking, patient participants rated this app with uncertainty, possibly for the lack of peer support, which has shown to result in improved patient-outcomes.[40,41] Patients in our study enjoyed being connected with their peers who were similar to them, and can offer "tips and tricks" and experienced wisdom. Therefore, apps that merge patients' need for peer support with digitally convenient features could be beneficial in facilitating their communication and awareness for community resources.[41,42]

Many of the identified facilitators and barriers to app use in COPD self-management differed between healthcare professionals and patients, and have been previously reported.[25,26,43,44] Facilitators for patients were related to the app interface, credibility and clinician endorsement,[25,26,44] with stronger interest in apps with interactive features.[42,45,46] While barriers were related to safety, confidentiality, privacy and lack of interest.[25,44] Healthcare professionals felt similarly, and emphasized the growing concern regarding misinformation and the potential for associated liability.[46,47] Stakeholders emphasized that apps should balance promoting motivation with avoiding overwhelming the users. Another barrier that was mentioned was the lack of app interest by the elderly population, possibly limiting their uptake, which was a previously reported assumption and barrier.[25,26] However, age should not be a perceived barrier, as our patients with an average age of 68.2 years were interested in using apps, only if they addressed their needs, without bombarding them with constant notifications and reminders. Stakeholders emphasized that introducing apps to patients must be a balance of motivation and considerations for patients' feelings of overwhelmingness, which could be mitigated with adequate education and digital health support.[17,25]

There was broad agreement with the idea that an app would have the capability to provide multiple features but also be customized based on patients' requirements.[42,45] Healthcare

professionals noted that patients' needs and engagement styles likely varied from theirs,[38,47] and advocated for app development through partnership and consultation with patient participants.[16,19,20] In agreement with previous studies, there was also emphasis on having one app that is "one size fits all", where an app would have the capability to provide multiple features but can be customizable based on patients' wants and needs.[42,45] Apps were considered to be supplementary to clinical care plans rather than substituting for them, with further evaluation being mindful of the existing inequalities and limitations to app accessibility, as these resources will require ownership of mobile devices and established infrastructure for successful uptake.[10,44] There is a need for further research on the use of apps for COPD self-management as supplemental resources for aging populations with diverse background education, language skills and comfort in technology.

Study strengths included having both people with COPD and healthcare professional stakeholder groups, evaluating the quality of apps easily accessible in the public domain and utilizing the MIND framework to identify potentially desirable features. Furthermore, we explored the public domain of COPD apps, a non-traditional area of focus, but an important one as the marketplace is dynamic and need constant evaluation. Our sample size enabled us to organize multiple focus groups rather than one group usually used in the RAND/UCLA method. This promoted participant expression and ensured that patients could share their opinions without being influenced in the presence of healthcare professionals.[37] The focus groups provided a rich source of information that supplemented the questionnaire responses.

Study limitations included a modest sized stakeholder group of people with COPD and their narrow age range. Since the apps did not have to be downloaded and trials, the collected feedback may have missed stakeholders' open perspectives on app usability and feasibility. As

the public app domain is dynamic, it is possible that newer products with more of the identified desirable features might have become available since study commencement. The list of public COPD apps in this study were based on our previous study as we wanted to maintain a consistent list to observe the similarities and differences between the research team and stakeholders' assessments.

4.6 CONCLUSION

Responding to a combination of survey questions and focus groups, patient participants and healthcare professionals rated only one of a small number of apps for COPD in the public domain as appropriate for self-management. This app incorporated features such as peer support, self-monitoring and education, which had been identified by participants as desirable components in a COPD app, developed by a credible non-profit professional organization. Stakeholders emphasized the need for apps to be customizable to address the varying patients' needs and that apps should be supplementary resources, rather than replacements for clinical management. As the public COPD app market grows, it is important to have a standardized system for evaluation that will direct users to the apps most likely to enhance their wellbeing.

4.7 SUPPLEMENTARY DATA

Item #1: Public COPD Apps infographic

https://mcmasteru365-my.sharepoint.com/:b:/g/personal/quachi1_mcmaster_ca/EdagVBi66m5JpsXEXhKAvwMBqwCwr8G4c5183VnPDf0TwQ?e=3GycK3

Item #2: Questionnaire for RAND/UCLA

https://mcmasteru365-my.sharepoint.com/:b:/g/personal/quachi1_mcmaster_ca/EWAouIE1Nk5PgyAP-fA4J48BdGft1mmKFg6uBvDISU-KJA?e=egQK4f

Item #3: Post-Round 1 summary sheet for participants (prior to focus group meeting)

https://mcmasteru365-my.sharepoint.com/:w:/g/personal/quachi1_mcmaster_ca/EZZiYC1913RFgw-q2a8ricsBUMA_t6Mqh2J70FC2b3CDqQ?e=xotUkX

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CHAPTER 5: DISCUSSION AND CONCLUSIONS

5.1 DISCUSSION

5.11 SUMMARY OF STUDIES

People living with COPD have expressed the need for additional resources to support their self-management and the recent COVID-19 pandemic has led to the increased popularity of mHealth apps for chronic lung diseases (CLD). However, the proliferation of available mHealth apps reported in the literature and in public marketplaces are overwhelming, making clear reporting of their characteristics and qualities necessary.[1-3] Detailed reporting ensures transparency across trials, encourage knowledge building and would minimize risks in misinformation and health safety.[2-4] In this thesis, thorough assessments using the MIND framework were applied to demonstrate its feasible application to apps outside the mental health domain – specifically COPD. We have: 1) identified the common qualities and features included in COPD apps in past studies evaluating their effectiveness; 2) graded the qualities and features of public COPD apps; and 3) determined the appropriateness of current public COPD apps from the perspective of healthcare professionals and people living with COPD. Based on that work, we have more recently collaborated with Harvard Medical School to create a subsection on the MIND website to house our public COPD assessments, ensuring knowledge translation of our findings to relevant stakeholders: patients living with COPD and clinicians.

Currently, the effectiveness of mHealth apps for people living with CLD is unclear,[5,6] likely due to study heterogeneity.[7,8] In our systematic review (chapter 2), we found that most studies did not adequately report their app designs and characteristics beyond their features. Factors such as the current lack of standardized reporting and evaluation criteria for apps may explain the observed variabilities in app qualities and trial designs, perpetuating study

heterogeneities.[9] In addition, very few were found to be reassessed in bigger trials (e.g., myCOPD,[5,6] EDGE,[7,8] Propeller Health[9]) and many were not available to the public. App unavailability prohibited extensive review by our research team and likely eliminated the possibility of utilizing them in future trials by other research teams. Cumulatively, these limitations prevent the clear identification of which app components or apps, are best to integrate into clinical plans.[2,3] Therefore, standardized criteria for evaluating and reporting mHealth apps is crucial, a priority that is reiterated throughout the mHealth literature, across different health contexts.[2,3] There are several different evaluation tools available, but an ideal framework should facilitate informed decision making amongst clinicians and patients when mHealth apps are considered.[10] Therefore, the MIND framework, a comprehensive evaluation tool addressing uncommon app qualities,[11] may be the ideal framework to address this need.

Recognizing that mHealth apps may serve a special role in COPD self-management in the future, greater awareness of public COPD apps is fundamental.[12] The MIND framework was also applied to public COPD apps in our evaluation study to outline their current characteristics and qualities (chapter 3). In the Android and Apple app marketplace, countless mHealth apps were filtered under the *COPD* search term, but many were deemed irrelevant. Only a small handful were patient-facing and specific for COPD self-management, inconsistently available across the Android and Apple platforms, created by mostly for-profit or unknown developers. Differences between these public COPD apps brought forward concerns of their overall poor quality and safety risks, likely explained by the lack of regulation on their features and designs.[13] Common features in these apps were education and medication tracking, and alarmingly, information was usually not properly cited to consensus guidelines or emerging evidence.[14] There needs to be greater attention towards the abundance of questionable COPD apps accessible

to the public, as easy acquisition poses serious misinformation and safety risks for their users.[4,15] Unfortunately, factors including the lack of strict regulation in development, quality-control and monitoring, are hypothesized to be the culprits for the poor state of public COPD apps.[11,13,16,17] Overall, these apps have no clinical evidence to support their use, making them unsuitable for supporting COPD self-management at this time.

Although most public COPD apps surveyed in the marketplace were poor quality, they are free to download and are accessible to people in the public.[1,10,17] This accessibility potentiates the need for clinicians to be aware of the state of public COPD apps in case their patients have interest in these resources for personal use, to reduce risks for being misinformed.[4] Similarly, most public COPD apps were deemed inappropriate by interdisciplinary healthcare professionals and people living with COPD. In our study exploring the acceptability of public COPD apps (Chapter 4), people living with COPD only identified one app, while healthcare providers identified three apps that may be appropriate. The mutually agreed upon app was created by a non-profit organization, COPD Foundation, familiar to the surveyed stakeholders, which had incorporated various components of education, symptoms tracking and external resources.[18] Ideal and preferred app features and engagement styles were slightly different amongst people with COPD and healthcare professionals, with greater emphasis for education and peer support by people with COPD. In contrast, healthcare professionals were more interested in interactive components that are more likely to motivate patients.[19-21] Generally, these findings confirm past findings where qualitative studies have reported preferences in credible apps that can provide safe, motivating features without compromising data security and liability.[4,20,22] Regardless of these preferences, both stakeholders unanimously agreed that any app should be supplementary and customizable instead of replacing usual COPD self-management plans.

5.12 COMPARING COPD APPS IN THE LITERATURE AND PUBLIC MARKETPLACE

There were some interesting distinctions in the features reported in COPD apps utilized in RCTs compared to public COPD apps. COPD apps in the literature focused on building interactive features to provide interactive feedback and collaboration with healthcare teams.[23-25] These COPD apps had a mixture of passive and interactive features,[26,27] likely explained by the research teams' familiarity to the clinical evidence, incorporating disease-specific components and behaviour change frameworks to guide their app development.[5,28,29] [19,30,31] In comparison to public COPD apps, the most popular features were passive, including education and medication tracking features. However, these features are shown to be insufficient at motivating users to be autonomous over their disease management.[24,32-34] Although the best combination of app features is unknown, app development should still be guided by clinical evidence.[21] Considerations for utilizing behaviour change theories and implementation strategies may likely support successful app use for COPD self-management.[19,24] COPD self-management is an intricate and ongoing process, requiring people living with COPD to adapt behaviours and develop skills over iterative interactions with their healthcare providers.[19]

One common MIND domain that is infrequently or poorly reported is app privacy and security.[35] These characteristics are important considerations when considering mHealth apps in clinical care, and must be clearly outlined for their users.[12,13] Apps reported in the literature and existing in the marketplace do not consistently provide information about their privacy policies.[14,36] The MIND Framework specifies the importance of having privacy policies that are of appropriate reading level to their users, ensuring they understand how their data may be collected or used.[11,37] Without clearly mentioning the potential risks, this may elicit concerns of inadequate data security, a barrier in adopting mHealth apps in clinical care.[2,4,22]

Contrasting between COPD apps used in trials and available in the public marketplace, there is a need for strong clinical evidence to identify the best COPD apps in either space.[17,24,26,27,31] It is evident that the apps reported in the literature are not publicly available, and the public apps on the marketplace have not been trialed.[17,36] Many of the COPD apps in the literature may be supported for use by individual RCTs or pilot studies,[5-7,9,29] but many are not reassessed in larger clinical trials. Similarly, public COPD apps are advertised by most developers to be helpful for self-management, but there is no clinical data or clinician endorsement to support these claims, unlikely to benefits users (chapters 3 and 4).[31,38,39] These research gaps should emphasize the lack of knowledge growth surrounding existing COPD apps and the need for refocusing future studies to incorporate these priorities.

Heterogenous characteristics and qualities of mHealth apps across studies prevented clear understanding of their effectiveness, a common limitation reported in systematic reviews.[26,27,40] However, there are a few research groups that have continued to evaluate their apps in ongoing trials. For example, myCOPD created by mHealth, first reported by Farmer et al (2014)[7] has consistently updated and trialed myCOPD across different components of COPD care (https://mymhealth.com/studies). Though this specific app is unavailable to the public, this demonstrates transparency and the possibility to evaluate and use existing mHealth app interventions across studies and geographical locations. Similarly, public COPD apps have continued to be evaluated across evaluation studies, demonstrating efforts in supporting the awareness and advocacy for their safe use.[16,17,31,38,39] However, evaluating public COPD apps across studies are challenged by quick app changes and discontinuations, further limited by the lack of structured searching in the app marketplace, preventing reproducible app results each time.[41,42]

The current evidence surrounding the quality and use of public COPD apps demonstrate the early stages of ongoing work to monitor and address their quality, fulfilling the primary objective of this thesis. Irrespective of whether the apps exist in the literature or the public marketplace, there is insufficient evidence to recommend their use, drawing uncertainties from clinicians and people living with COPD. Although the primary and secondary objectives of this thesis were met, there must be continued efforts to build on the existing foundational knowledge to safely support the growth and use of mHealth apps in COPD care. Limitations experienced by apps in the literature and public marketplace could be alleviated with collaborations between the health scientific community and app developers, bridging gaps and mitigating safety concerns.

5.13 – KNOWLEDGE TRANSLATION AND IMPLEMENTATION

Evidence-based practices (EBP) is a crucial element of using research evidence to support clinical decision making to support high quality care for patients.[43] However, effective adoption of research into routine practices can take years, creating the knowledge to practice gap.[44] This phenomenon also applies to mHealth apps, with the knowledge gap exacerbated by the dynamic nature of app growth, modifications and lack of regulation.[13,45] Furthermore, since there is still uncertainty regarding mHealth app effectiveness, it is difficult to make strong recommendations for their use.[26,33,40] However, the pandemic and increasing interest of mHealth apps have exacerbated their quick adoption into patients' daily lives, even in the absence of strong evidence.[12,32] Although there is no "best-evidence" to direct the dynamic approach of creating, exchanging and implementing mHealth app use, clinicians and patients still require the knowledge to understand mHealth apps and their role in clinical practices.[44,46] Therefore, attention to translating emerging evidence is necessary to address the ongoing need of evidence-based recommendations on mHealth app development and use.

A key component of effective knowledge translation is the use of appropriate implementation strategies, by utilizing theories, frameworks and models to facilitate knowledge mobilization, integration and sustained use.[43,45-48] With the emerging evidence on mHealth apps for COPD self-management, clinicians and patients need to be aware of them, especially those in the public domain (discussed in chapters 3 and 4). Therefore, a feasible and adaptable solution is needed to continuously evaluate their quality to ensure safety by using a stable process to mobilize the knowledge of emerging COPD apps and research to inform decisions surrounding their use in patients.

The Knowledge to Action (KTA) cycle is a well-known conceptual framework that outlines the process in knowledge exchange and implementation across stakeholders.[46,49,50] There are two phases in the KTA cycle: 1) knowledge creation; and 2) action cycle, aimed at drawing the connection between research inquiries and clinical practices.[50] These two phases can occur simultaneously to inform each other, demonstrating its fluidity in allowing for adaptability to the ongoing needs and changes.[48,51] This makes the KTA cycle a desirable and fundamental approach to address evolving research, needs and use of mHealth apps for COPD self-management.

Overall, there is a lack of knowledge mobilization and implementation to meet the increasing interest and inquiry towards mHealth apps for rehabilitative purposes.[2,12,36,52,53] The KTA cycle is one of the most common implementation process model used to promote behavioural changes and tailored intervention in rehabilitation health.[46,51] Thus, using the KTA cycle to optimize its applicability to mHealth apps by integrating app-specific processes may be ideal. In a pilot study, Camacho and colleagues reported an implementation effort utilizing the Technology Evaluation and Assessment Criteria for Health apps (TEACH-apps) process, a

strategic approach in evaluating public mental mHealth apps with relevant stakeholders, in an objective manner.[10] The TEACH-Apps process was informed by past theories and frameworks to generate an approach that includes 4-steps: 1) pre-condition; 2) pre-implementation; 3) implementation; and 4) maintenance evolution. The TEACH-Apps process was intended to be widely applied across all health disciplines, aimed to increase engagement with relevant stakeholders in app evaluations for clinical use.[10] Shortly after, the authors of the TEACH-apps process were involved in creating the MIND website (https://mindapps.org/), a global knowledge translation effort to provide information on public mHealth apps to relevant stakeholders using an evidence-based approach.

The overarching objectives and phases between the KTA cycle and TEACH-app frameworks share similarities. Together, they have the foundational components to create a cohesive process to address the knowledge gaps in COPD mHealth apps in the public space, formulating the knowledge translation plan of this thesis (Figure 1). The KTA cycle served as the guiding process to further develop the TEACH-app process, where the KTA knowledge creation phase was integrated within the *Precondition* stage, with the KTA action phase aligning with the 4-steps outlined above (Figure 1). Subsequently, the MIND evaluation framework informed the systematic reviewing, reporting and maintaining of public COPD apps and leveraging the MIND website for widespread sharing (Figure 1 and 2). This modified process entails three main steps: 1) pre-conditions and pre-implementation; 2) implementation; and 3) maintenance and evolution, outlined in Figure 2. The final evaluated public COPD apps from this study are currently housed on the MIND website, searchable by the *Supported Condition* filter à COPD (Figure 3).

Knowledge translation and implementation of mHealth apps for COPD self-management is still emerging. There is an abundance in knowledge creation surrounding this topic, but further

work needs to address knowledge mobilization and implementation to understand their real world applications.[44,53] Consolidation of these public mHealth app evaluations would inform clinicians and patients of their quality before use, and open doors to new studies on their effectiveness. This collaboration and public translation of results is to provide and advocate widespread knowledge mobilization of this mHealth research beyond the scientific community. Public and global dissemination is a channel that will facilitate and emphasize the continuous need for information sharing to the most important stakeholders: healthcare professionals and people living with COPD.

Figure 4: Proposed flow cycle of facilitating the research and knowledge acquisition on COPD apps for self-management using the TEACH-app process and KTA cycle. Steps of the TEACH-apps process is illustrated in the center, surrounded by the elements in the action phase of the KTA cycle, demonstrating their alignment in priorities. *The pre-condition stage of the TEACH-App process focuses on the identifying the relevant information and apps for the subsequent stages; this purpose overlaps with the knowledge creation phase of the KTA cycle where the aim is to produce knowledge before implementation.

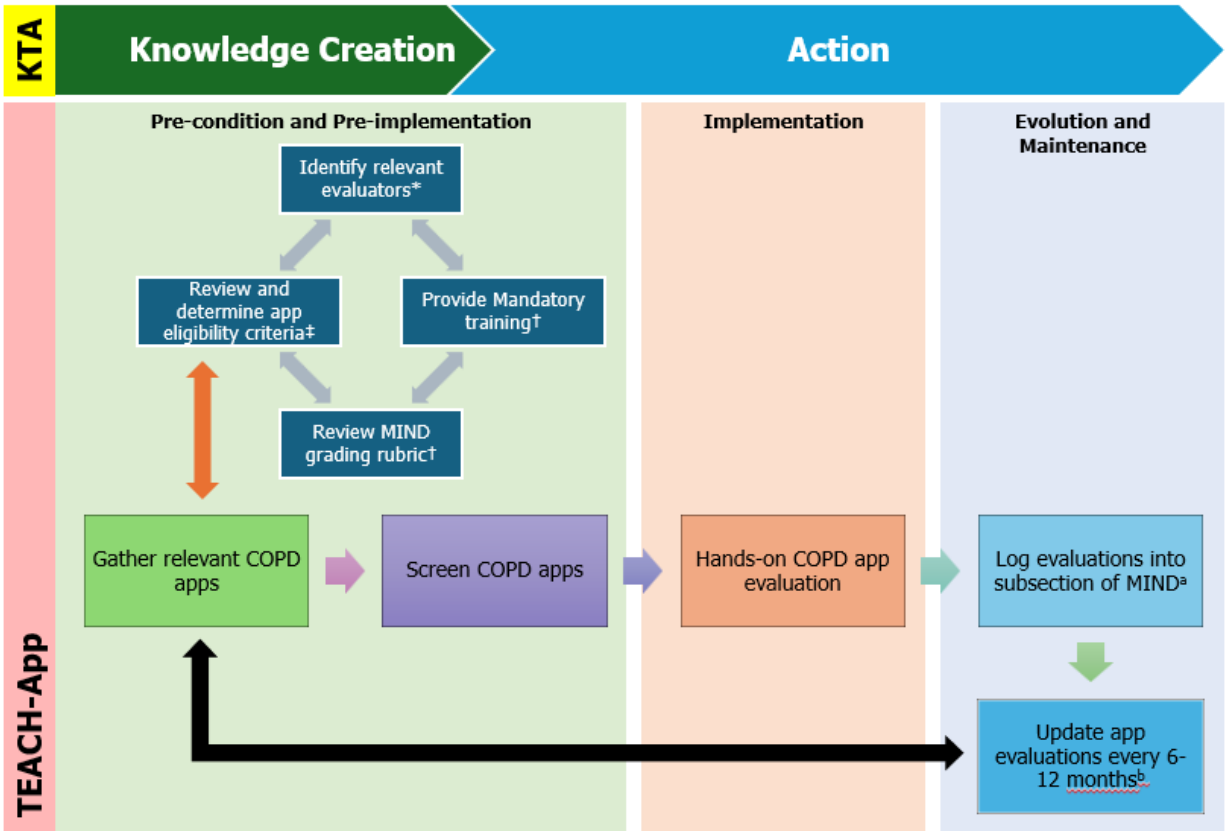

Figure 5- Flow diagram of the proposed process across the 3 steps: 1) Pre-condition and pre-implementation; 2) Implementation; 3) Evolution and Maintenance, derived from the TEACH-app framework,[10] within the overarching phases of the KTA cycle. †App raters' mandatory (virtual) training will be provided by the research assistant from the Division of Digital Psychiatry, either individually or as a small group. ‡Apps' eligibilities are based on the criteria implemented on the MIND platform and could be modified by the stakeholders to address priorities and needs.

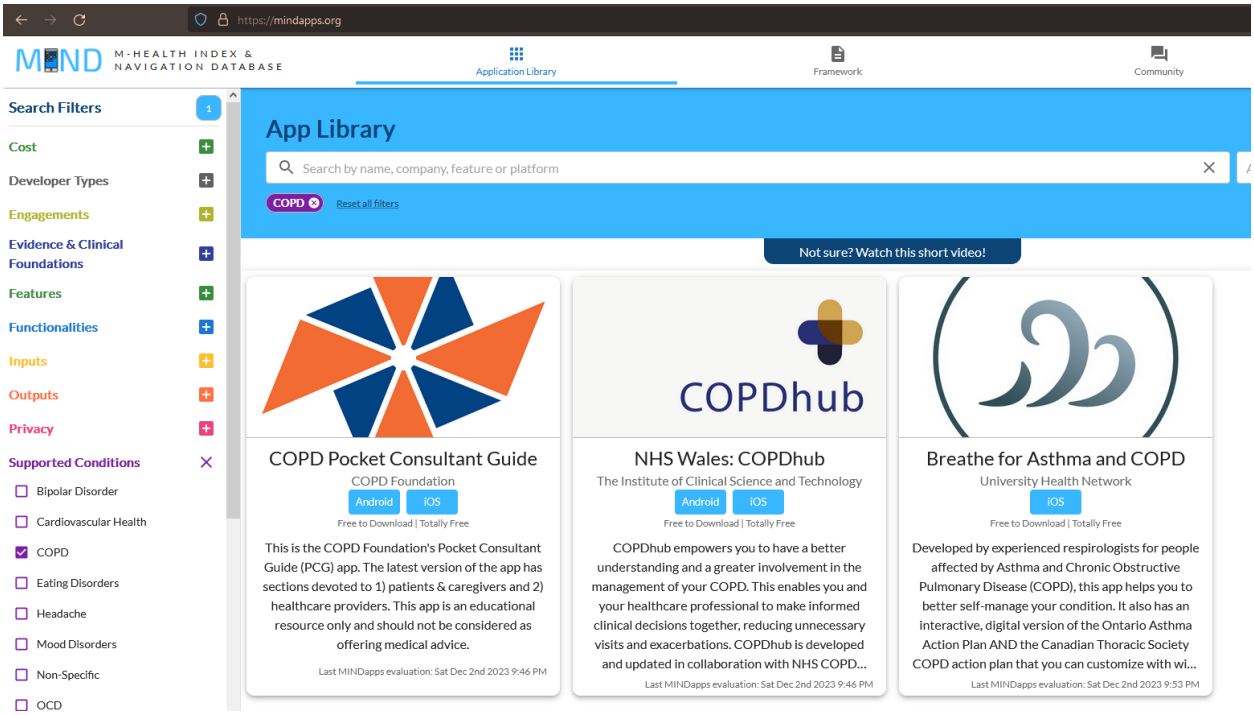

Figure 6- The MIND website currently houses the MIND evaluations for several patient-facing, COPD apps. These apps are searchable by the search bar above and by "Supported conditions" filter on the left hand side. https://www.mindapps.org

The plan is to continue this effort to review and maintain the evaluations of public COPD apps as the marketplace evolves. Informed personnel from the relevant stakeholders' community will be recruited to support the ongoing TEACH-Apps process, advocating for safe and credible navigation around public COPD apps. This international and multidisciplinary partnership between Harvard Medical School and health disciplines within the COPD healthcare community to facilitate knowledge exchange and application to improve health outcomes.[47]

5.14 – IMPLICATIONS TO HEALTHCARE PROFESSIONALS AND PATIENTS

Successful knowledge translation requires four elements as defined by the Canadian Institutes of Health Research (CIHR). CIHR considers knowledge translation to be an dynamic implementation process, incorporating elements of knowledge synthesis, dissemination, exchange and application to enhance care.[47] However, knowledge translation regarding mHealth

for COPD care is still in its early infancy as outlined above. Although mHealth apps fall under the category of medical devices, mHealth technologies and apps are rapidly evolving software that do not conform to the traditional definitions of medical hardware devices.[13] This has resulted in the lack of regulatory framework and guidance for mHealth technologies, eliciting uncertainties within healthcare professionals and their subsequent knowledge users.[13]

The clinical significance of leveraging the MIND website is to ideally address clinicians' and patients' need for guidance in navigating the mHealth app domain, especially in the public marketplace. This informative website and tool could alleviate the challenges in unfamiliarity and questionable credibility of apps, common reasons for hesitation amongst the stakeholders.[4,22] One of the strengths of the MIND website is the alignment of knowledge sharing – there is only one version of the information publicly available (Figure 4). COPD apps' features, characteristics and qualities are easily viewed and straightforward, ensuring the main points are conveyed. For clinicians, it is a resource they can refer to when making informed decisions around COPD apps, and whether the chosen app has the appropriate qualities for their clients. Furthermore, clinicians can share these evidence-based evaluations to their clients, facilitating the collaborative decision-making process in introducing apps into care plans and supporting client autonomy for disease self-management.[19,29,30,54]

With the increased interest in mHealth apps, mHealth apps will likely continue to be a viable resource for patients.[22,30,55] E-literacy is a common barrier to knowledge users (patients) of mHealth apps, possibly deterring users away from this potential tool.[22,56-59] However, by displaying app evaluations on the MIND website, it will enhance the transparency and ease of information sharing to the intended knowledge users, our patients, hopefully to address this barrier. Furthermore, encouraging knowledge users to participate in using the MIND platform to

inform their decisions around COPD app usage, perhaps this opens opportunities for engagement to ensure these apps are also evaluated by this important stakeholder.

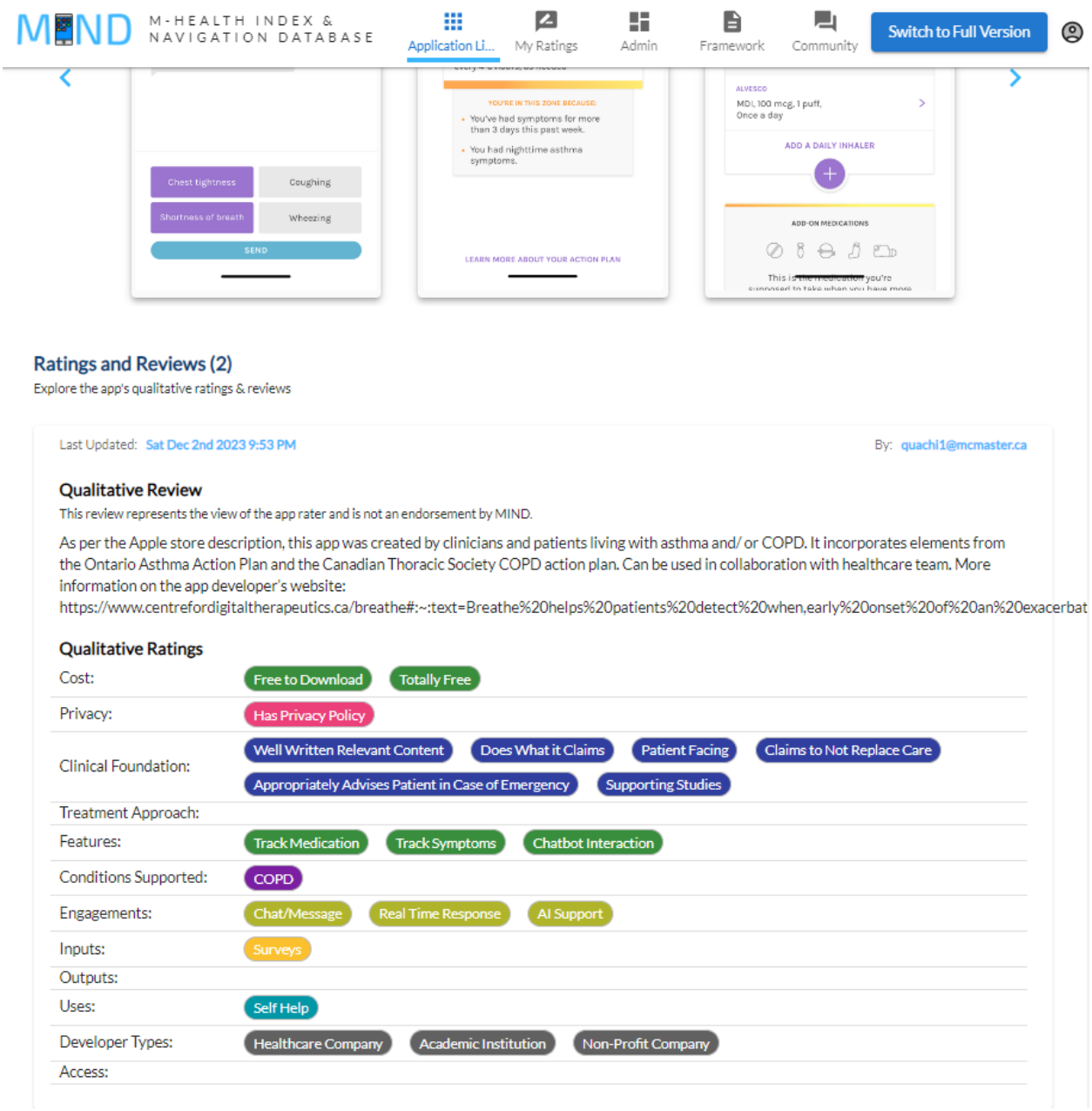

Figure 7 – Print screen of a COPD app evaluation on the MIND website. The evaluation across the different domains of the MIND framework is succinctly summarized and visually easy to read and digest.

5.15 – IMPLICATIONS TO RESEARCHERS

MHealth apps for COPD self-management are still relatively new and unexplored, especially with the limited data that exist for both research-informed and public COPD

apps.[14,16,26,27,31] Researchers need to prioritize evaluations in addressing the knowledge gap in COPD mHealth apps created by heterogenous study designs and variable COPD app qualities. Attention towards to public COPD apps should be a priority, as public accessibility facilitates use, regardless of safety and credibility.[22,58] With the MIND website, researchers can refer to this internationally managed database to seek the appropriate COPD apps for their studies to evaluate effectiveness and successful implementation. In turn, this will generate new data for the repository, fostering the advancement of accessible, credible and effective tools for patient care.

5.2 STRENGTHS AND LIMITATIONS

There were several strengths to the studies conducted in this thesis. To our knowledge, this is the first time the MIND framework was utilized to evaluate mHealth apps in the lung health space. There are several mHealth app evaluation tools and the mERA checklist available[1,3,60]; however, they were not as comprehensive as the MIND framework. Most evaluation tools and checklists are limited, usually focusing on features and clinical effectiveness, missing components, such as privacy and security.[11,35] Using the MIND framework across the systematic review and assessment study, we demonstrate the possibility to consistently apply this comprehensive framework. Concentrating on public COPD apps, a non-traditional area of focus, we have emphasized the need for stakeholders' input and the importance of disseminating these results. Furthermore, we are collaborating with the research team at Harvard Medical School to house the MIND assessments of several public COPD apps identified in our assessment study. This knowledge dissemination approach is an advancement towards providing clarity on public COPD apps to the public, which may include clinicians and people living with COPD. Hopefully, this approach will encourage other researchers and mHealth app users to consider using MIND framework within the processes of the KTA cycle

and TEACH-App process. This thesis demonstrated the practicality of implementing the MIND framework within the KTA cycle and TEACH-App process and can be further refined to incorporate emerging knowledge translation theories and models.

There are a few limitations to note. There was greater attention and emphasis on free to download and English-only public COPD apps. Although our assessment revealed the most public COPD apps to be poor in quality, it may be possible for paid COPD apps to be better in quality and have greater potential for supporting COPD self-management. There is a correlation between mHealth app cost and quality, as greater costs may allow for improved features and regular maintenance to minimize safety risks.[61,62] However, free COPD apps were the primary focus because cost, no matter how small, is regarded as an accessibility barrier,[22,58] and is a common reason for app abandonment.[61] And unlike indexed databases, a strategic search strategy is not possible with Apple and Android marketplace. Instead, search results in these app stores are likely fueled by the algorithm that is designed to promote and aid in commercial profit. The inability to perform a structured search and to revisit the results list is a known limitation in previous work, challenging researchers with manual tracking and unstructured screening that may have missed eligible public COPD apps for review. The COPD apps included in the systematic review and evaluation studies are current to the time they were conducted, as apps are constantly evolving and changing. It is possible for the apps presented in this thesis to be considered out-dated, which is an ongoing challenge in app research.[31,39,41,42] Finally, moderately-sized stakeholder groups were involved, especially our group of people living with COPD, which may limit broader application of the findings reported.

5.3 NEXT STEPS: FUTURE DIRECTION

It is frequently reiterated in the literature that more research on mHealth apps is needed, with various knowledge gaps that should be addressed in ongoing and future work. Future direction of mHealth app research should include three foci: 1) continuing to evaluate public COPD apps via the MIND website and considering their use in future studies; 2) standardizing the reporting method of mHealth apps for future trials; and 3) research on publicly available apps to determine effectiveness.

There is a need to focus on public COPD apps, as evaluating these apps and monitoring their qualities are crucial to ensure their accuracy and safety over time.[4,10,11,14] As there is no regulation surrounding app development and availability in Canada, app assessment and assessment maintenance are crucial, yet a challenge.[1,13] The current effort demonstrated with the MIND website is a great example of managing this task (https://mindapps.org). Our current collaborations with the MIND team, and anticipated partnership with our relevant stakeholders should enable this work to act as a precedence for the need to continue this initiative beyond the COPD community. To further enforce MIND Framework adoption and attention to their website, mitigating approaches to dissemination, such as delivering workshops, lectures, podcast discussions and engaging public members, are necessary. To date, the MIND team have employed several of these dissemination approaches, with increasing use of the MIND Framework in emerging research.[42]

Furthermore, standardization of the reporting method of mHealth apps in future clinical trials are necessary and should be enforced. There are multiple tools to guide the reporting of mHealth app research,[1,60] but the EQUATOR endorsed mERA checklist should be consistently used across interventional studies.[3] For complete thoroughness, additional details such as app

privacy and security infrastructure, accessibility, reading level, engagement styles, and interoperability for data sharing should also be outlined in these reports.[35,63] Reporting of these details can also be supported and guided by the existing MIND framework,[11] an effort to overcome the challenges in app variability, focused on data privacy and security, with beneficial qualities to effectively measure clinical outcomes.[64]

Lastly, more research on mHealth apps is necessary to understand their effectiveness, successful implementation and long-term benefits. There is a need to evaluate publicly available apps that are free and reasonably priced to determine their quality and effectiveness. App costs is a common barrier, but patients may consider paid apps if the benefits outweigh the small cost.[61] Furthermore, if mHealth apps are shown to be significantly beneficial and cost-effective, future studies need to address the facilitators and barriers to their integration into healthcare plans over time.[62,64] To date, there are limited studies that followed patients up to 1-year post-intervention, with poor retention.[40,65,66] Integrating mHealth apps into patients' daily-lives for self-management likely requires elaborate knowledge translation and implementation efforts, as motivation to sustain mHealth app behaviours will likely differ across populations.[2,22,58,64] Additionally, there are many structural and contextual factors to consider when designing and implementing mHealth apps, factors that must be addressed, such as patients' technology literacy, accessibility and facilitators, and barriers for use.[22,56,58]

5.4 CONCLUSIONS

We have successfully used the MIND framework and consulted with the COPD care community to inform our evaluations of public COPD apps, fulfilling components of the TEACH-Apps process. These evaluations are publicly available on the MIND website, and this demonstrates the first few steps toward open knowledge translation of COPD app research. The

current state of mHealth apps, especially those in the public marketplace, need much more research to fill the knowledge gaps to better understand their efficacy and limitations. Future research will need to consider using standardized reporting and evaluation approaches, along with mitigating barriers and accessibility constraints for mHealth apps within and beyond COPD self-management.

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