# The use of Mobile Health in the management of Chronic Obstructive Pulmonary Disease

by
© Meshari Fahad Alwashmi
A Thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for the degree of Doctor of Philosophy

**School of Pharmacy**
Memorial University of Newfoundland

**May 2020**

St. John's Newfoundland

Abstract

The prevalence and mortality rates of chronic obstructive pulmonary disease (COPD) are increasing worldwide. Therefore, COPD remains a major public health problem. Using an mobile health (mHealth) intervention has the potential to enhance COPD treatment outcomes while mitigating healthcare costs. However, the complexity of the process of developing an mHealth intervention for COPD management is poorly understood, and in-depth assessment of the development process of mHealth interventions for COPD management is currently lacking.

This thesis advances our understanding of how to apply the human-centered design process when developing an mHealth intervention for COPD management. The thesis is composed of the following five interconnected journal articles:

1. A systematic review and meta-analysis to *summarize and quantify the effect of mHealth interventions* on patients with COPD;
2. A qualitative study to explore the *perceptions of healthcare providers* regarding an mHealth intervention for COPD management;
3. A mixed methods study to explore the *perceptions of patients with COPD* regarding an mHealth intervention for COPD management;
4. A qualitative study to *identify the features* of an mHealth intervention for COPD management; and,
5. A mixed methods approach, the iterative convergent design, to guide the *usability testing* process for mHealth interventions.

The outcomes of this research contribute to knowledge about the use of mHealth in COPD management. Firstly, this thesis provides an overview of the effectiveness of mHealth in COPD management. Secondly, it provides an understanding of how to actively and efficiently

involve users in the design and development of health information technology. Thirdly, it provides recommendations regarding the features of an mHealth intervention to enhance COPD management. Lastly, it proposes a mixed methods framework for mHealth usability testing. The application of the proposed methods is demonstrated using different case studies. This program of research highlights the process of developing an mHealth intervention for COPD management. Application of the findings could help others in the field to further investigate the development of mHealth interventions in this area.

## Dedication

This thesis is dedicated to my beloved family for their endless love and continuous support in my journey. You know I couldn't have done this without you. To my mother, for encouraging me to be a pioneer in my field and always reminding me to revisit the purpose of my work. To my father, who inspires me to be a kind human and to think outside the box. To my siblings, for always being there to answer my calls and reminding me that I am not alone. I am nothing without you.

# Acknowledgements

I would like to express my deepest appreciation to everyone who has supported me throughout the completion of this graduate program. I would like to sincerely thank my primary supervisors Dr. John Hawboldt and Erin Davis for their support and encouragement. You have allowed me to have a truly unique learning experience in thought this program of research. I would like to acknowledge the support of Dr. Hawboldt that led me to an interesting academic topic. He works so efficiently and I can always get his timely and valuable responses.

I would also like to acknowledge the assistance of my supervisory committee members, Dr. Beverly Fitzpatrick, Dr. Jamie Farrell, Dr. John-Michael Gamble, Dr. Hai Nguyen, and Dr. Gerard Farrell for your feedback and direction throughout this project. I will never forget Dr. Fitzpatrick's encouragement during the process. We had extensive meetings to guide me through the design, analysis, and write-up of the thesis and manuscripts. This research would not be possible without the help of Dr. J. Farrell that has made recruiting research participants possible. Thank you to all the participants in the survey and interviews, your input and insights were invaluable to my research.

My gratitude to my friends for their continued support during my Ph.D. life journey. They shared joy, curiosity, and passion from the first day. Specifically, Dr. Mugford for his support, encouragement, and fostering that allowed me to become a better scholar and person. Finally, I would like to acknowledge the funding from the Saudi Arabian Cultural Bureau and Mitacs that made it possible for me to pursue studies as a full-time graduate student.

# Table of Contents

# List of Tables

# List of Figures

## List of Abbreviations

**Apps:** Applications

**CCHS**: Canadian Community Health Survey

**CG:** Control Group

**CIHI:** Canadian Institute for Health Information

**COPD:** Chronic Obstructive Pulmonary Disease

**GOLD**: Global Initiative for Chronic Lung Disease

**HCD:** Human-Centered Design

**HCP:** Health Care Provider

**IG:** Intervention Group

**ISO:** International Organization for Standardization

**JMIR:** Journal of Medical Internet Research

**mHealth:** Mobile Health

**MMR:** Mixed Methods Research

**N/R:** Not Reported

**NL:** Newfoundland and Labrador

**NRCT:** Nonrandomized Controlled Trial

**PHAC**: Public Health Agency of Canada

**PI:** Primary Investigator

**PRISMA:** Preferred Reporting Items for Systematic Reviews and Meta-Analyses

**RCT:** Randomized Controlled Trial

**SD:** Standard Deviation

**SOB**: Shortness of Breath

**SUS:** System Usability Scale

**UCD:** User-Centered Design

**USPSTF:** US Preventive Services Task Force

**WHO**: World Health Organization

## List of Appendices

# Chapter 1: Introduction

## 1.1 Overview

This dissertation aims to investigate how to apply the human-centered design (HCD) process when developing an mobile health (mHealth) intervention for Chronic Obstructive Pulmonary Disease (COPD) management. It will investigate various topics including the current state of COPD management using mHealth, the perceptions of patients with COPD and their healthcare providers regarding the use of mHealth in COPD management, and the perceived features of an mHealth intervention that could aid in managing COPD. Lastly, we provide a novel mixed methods framework on how to test the usability of an mHealth intervention.

This chapter presents the background of my Ph.D. program of research. It provides an overview of the focus and design: COPD, mHealth, HCD, and Mixed Methods Research (MMR). The knowledge gap and research questions will be discussed. The last section outlines the structure of the thesis.

### 1.1.1 Chronic Obstructive Pulmonary Disease

#### *1.1.1.1 Definition and Etiology*

The Global Initiative for Chronic Obstructive Lung Disease (GOLD) defines COPD as follows:

> a common preventable and treatable disease that is characterized by persistent respiratory symptoms and airflow limitation that is due to airway and/or alveolar abnormalities caused by significant exposure to noxious particles or gases (GOLD, 2019, p. 4).

COPD encompasses a spectrum of diseases, including chronic bronchitis and emphysema, with most individuals having some characteristics of both (Kim & Criner, 2013).

Chronic bronchitis affects the epithelium of the central airways (Hogg, 2004). It is diagnosed by a persistent cough that produces sputum and mucus for at least three months in two consecutive years (GOLD, 2019). In chronic bronchitis, airway obstruction occurs because inflammatory cells drive the exaggerated mucus production, which causes the airways to narrow (Kim & Criner, 2013). The narrowing of airways keeps air from reaching the alveoli and prevents the lungs from emptying fully (O'Donnell et al., 2008). Mucus hypersecretion develops as a consequence of several factors, including cigarette smoke exposure, viral infection, and bacterial infection (Kim & Criner, 2013). Emphysema is characterized by the destruction of the gas-exchanging surfaces of the lung (alveoli) (GOLD, 2019). This reduces the total surface area available for gas exchange, which leads to poor oxygenation of the blood (Phal & Sharma, 2019).

Various risk factors have led to the increased prevalence of COPD. The primary cause is tobacco smoke, including second-hand or passive exposure. Another risk factor is exposure to air pollution, such as in the use of biomass fuels. Occupational exposure to dust causes shortness of breath (SOB), thus avoiding dust may reduce COPD exacerbations (GOLD, 2019). Also, genetic factors may play a role in increasing the risk of COPD. This includes the deficiency of alpha-1-antitrypsin, an anti-protease that protects the lung tissue from damage and predisposes patients to COPD (GOLD, 2019).

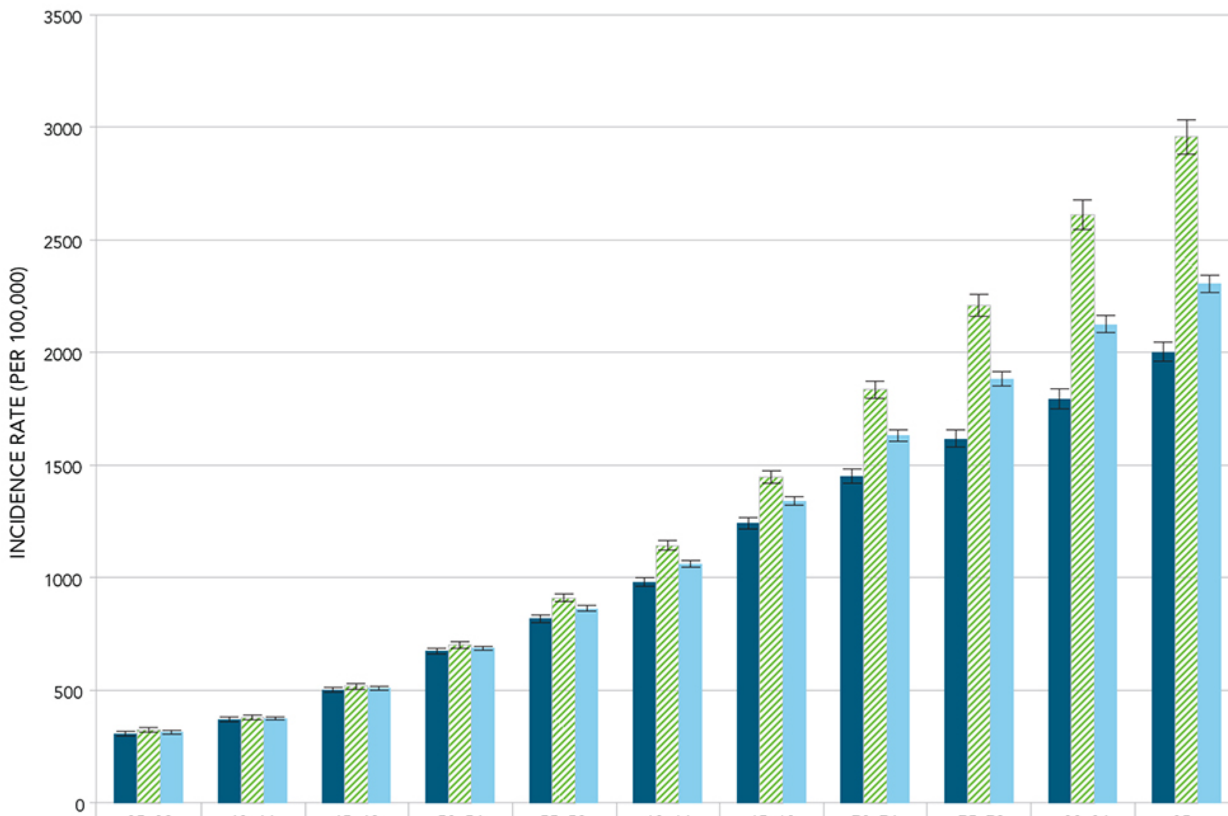
#### *1.1.1.2 Prevalence and Incidence Rates*

*Worldwide:* The prevalence and mortality rates of COPD are increasing worldwide. Therefore, COPD continues to be a relevant public health problem. The COPD prevalence rate is rising due to the increasing prevalence of smoking in developing countries and the ageing population in high-income countries (GOLD, 2019). In 2008, the World Health Organization

(WHO) predicted that COPD will become the third leading cause of death by 2030 globally. COPD affected approximately 329 million people (4.8% of the global population) in 2010, which is much higher than the earlier figure of 64 million in 2004 (Vos et al., 2012).

*Canada:* Although COPD is a preventable and treatable condition, it is the fourth leading cause of death in Canada (Statistics Canada, 2011). In 2008, approximately 4.6% of the Canadian population (aged 35 and over) reported that they had been diagnosed with COPD (Statistics Canada, 2011). This rate almost doubled to 8.3% in 2017 (Statistics Canada, 2019). Direct measurements of lung function from the Canadian Health Measures Survey ([CHMS], 2013) indicated that 13% of Canadians had a lung function score indicative of COPD, which is three times higher than the reported rate (Statistics Canada, 2013). This disparity between reported and measured COPD in the CHMS suggests the underdiagnosis of the disease in Canada (Evans et al., 2014). The incidence rates of COPD in Canada for 2011–2012 increased steadily for both males and females across the lifespan (Figure 1.1). Overall, the incidence rates ranged from 317.7 per 100,000 people in the 35–39 age group, to 2309.6 per 100,000 people in the 85 and older age group (Public Health Agency of Canada [PHAC], 2018). Among men, COPD rates increased steadily from age 35 and remained high; on the other hand, women's COPD rates increased from age 35 but it was lower than men at age 65 and above.

The current study was conducted in Newfoundland and Labrador (NL). In 2013, the NL population aged 35 and over who reported being diagnosed with chronic bronchitis, emphysema, or COPD by a health professional was 4.9% (Statistics Canada, CCHS, 2013).




| | 35–39 | 40–44 | 45–49 | 50–54 | 55–59 | 60–64 | 65–69 | 70–74 | 75–79 | 80–84 | 85+ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Females | 309.6 | 375.2 | 506.1 | 677.4 | 821.6 | 983.5 | 1246.6 | 1455.4 | 1621.6 | 1796.9 | 2006.0 |
| Males | 326.9 | 382.3 | 521.5 | 703.5 | 914.5 | 1147.4 | 1450.6 | 1838.7 | 2212.8 | 2613.2 | 2961.0 |
| Total | 317.7 | 378.7 | 513.8 | 690.5 | 867.8 | 1063.8 | 1346.0 | 1635.0 | 1886.3 | 2129.5 | 2309.6 |

AGE GROUP (YEARS)

**Figure 1.1:** Incidence rates of diagnosed COPD among Canadians aged 35 years and older, by age group and sex, Canada, 2011–2012.

Estimates of the prevalence and incidence of COPD are dependent upon the definition and diagnostic guidelines of COPD. For example, some studies rely on pre-bronchodilator spirometry for diagnosing COPD; alternatively, other studies recommend post-bronchodilator spirometry, which implies that the best possible lung function of an individual should be used to classify the disease (Evans et al., 2014). This variability limits the comparability of the prevalence and incidence between studies.

#### *1.1.1.4 Prognosis*

An acute exacerbation of COPD is defined as an acute worsening of respiratory symptoms that results in additional therapy (GOLD, 2019). It has detrimental effects on lung function, health-related quality of life (HRQL), and exercise capacity (Suh, Mandal, & Hart, 2013). Exacerbations cause an increase in hospitalizations, relapses, and hospital readmissions (Matkovic et al., 2012). Although COPD exacerbations are responsible for the majority of the morbidity and mortality of COPD, little is understood about their cause, prevention and treatment (Criner et al., 2015; Miravitlles et al., 2013). COPD exacerbations negatively impact health status, rates of hospitalizations, and disease progression (GOLD, 2019).

COPD is associated with multiple comorbidities, including ischemic heart disease, osteoporosis, glaucoma, malnutrition, anemia, peripheral muscle dysfunction, cancer, metabolic syndrome, and mental disorders (O'Donnell, 2008). Patients have a greater morbidity and mortality when COPD is present as a comorbid condition compared to when its absent (GOLD, 2019).

Smoking is directly responsible for approximately 80% of deaths from COPD (US Department of Health and Human Services, 2014). Quitting smoking has been associated with improved lung function, reduced chronic cough and airway mucus production, and decreased mortality from COPD (PHAC, 2012). All-cause mortality rates were higher among Canadians living with COPD than those without COPD across all age groups; the rate ratios ranged from 4.7 in the 35–39 age group to 1.7 in the 85 and older age group (Statistics Canada, 2018). By 2030, there may be over 4.5 million deaths annually from COPD-related conditions (Lopez et al., 2006; WHO, 2019). In China, which has one-third of the world's smokers, the current predictions of the annual COPD mortality rate will be over 2 million by 2033 (Lin et al., 2008).

#### *1.1.1.4 Economic burden*

COPD imposes a significant economic burden on healthcare systems. The Conference Board of Canada stated that the combined direct and indirect costs of COPD would increase from just under $4 billion in 2010 to about 9.5 billion by 2030, an increase of 140 percent (Thériault, et al., 2012). In 2010, the three major chronic lung diseases: asthma, COPD, and lung cancer, are costing Canada's economy $12 billion with the annual economic burden predicted to double by 2030 if strategies to manage the respiratory disease are not developed (The Conference Board of Canada, 2012).

In 2011, Statistics Canada conducted a **"**Survey on Living with Chronic Diseases in Canada" (SLCDC)**.** The survey included a nationally representative sample of 1,133 Canadians aged 35 years and older who reported being diagnosed with COPD by a health professional. They stated that COPD is devastating in nature and negatively impacts an individual's quality of life. Among Canadians with COPD, 45% reported their overall health as "fair or poor" (PHAC, 2012). COPD affected their activities of daily living and occupational status by reducing the number of hours worked or changing the type of work. As COPD progresses, it limits the quality of life and activity levels due to SOB. According to the Canadian Institute for Health Information [(CIHI), 2008], COPD now accounts for the highest rate of hospital admissions among major chronic illnesses in Canada. In addition, it has a much higher readmission rate than other chronic illnesses (CIHI, 2008).

Respiratory diseases pose a significant economic burden to the Canadian healthcare system due to both direct and indirect costs. Currently, almost 6.5% of total healthcare costs are related to respiratory diseases (not including lung cancer) (PHAC, 2007). The direct costs are a result of outpatient and inpatient care expenses; alternatively, the indirect costs arise due to the loss of productivity. Mittman et al. stated that hospital admissions for COPD lung exacerbations averaged a 10-day length of stay at a cost of $10,000 per stay (Mittman et al., 2008). They estimated the total cost of COPD hospitalization in Canada to be $1.5 billion a year (Mittman et al., 2008). Dynamic modeling has shown that any intervention that can reduce the number of exacerbations in a population will have a substantial impact on the morbidity and costs of COPD (Najafzadeh et al., 2012; Theriault et al., 2012).

#### *1.1.1.5 Diagnosis*

Unfortunately, about 60–85% of patients with COPD, especially in its mild to moderate stages, remain undiagnosed (Decramer et al., 2012). GOLD (2019) stated that a clinical diagnosis of COPD should be considered in any patient who has SOB, chronic cough or sputum production, a family history of COPD, and a history of exposure to risk factors of the disease, such as tobacco smoke, smoke from home cooking and heating fuels, and occupational dusts and chemicals (GOLD, 2019). Spirometry is the primary diagnostic tool for COPD. Forced expiratory volume in one second ($FEV_1$) is the volume exhaled during the first second of a forced expiratory maneuver started from the level of total lung capacity. Forced vital capacity (FVC) is the amount of air that can be forcibly exhaled from the lungs after taking the deepest breath possible. The presence of a post-bronchodilator $FEV_1$/ FVC $< 0.70$ confirms the presence of persistent airflow limitation (GOLD, 2019). Elbehairy, Webb, Neder, & O’Donnell (2013) recommend screening by spirometry in smokers at risk. Other strategies that may be considered as part of the diagnosis and assessment of COPD include chest radiographs, lung volumes and diffusing capacity, oximetry and arterial blood gas analysis, alpha-1 antitrypsin deficiency screening, exercise testing, and composite scores (GOLD, 2019).

The degree of airflow limitation is classified based on post-bronchodilator $FEV_1$. Patients with COPD are classified into four grades: GOLD 1 has a mild airflow obstruction with $FEV_1 \geq$ 80% of predicted; GOLD 2 has a moderate airflow obstruction with $FEV_1$ 50–80% of predicted; GOLD 3 has a severe airflow obstruction with $FEV_1$ 30–50% of predicted; and GOLD 4 has a very severe airflow obstruction with $FEV_1 < 30\%$ of predicted. This definition provides an objective method for classifying the severity of airflow limitation in COPD. Due to the weak correlation between FEV1, symptoms, and a patient's health, a formal symptomatic assessment is required to classify the severity of the airflow (GOLD, 2019; Han et al., 2013; Jones et al., 2009). These symptomatic assessments include the modified British Medical Research Council (mMRC) Questionnaire, the COPD Assessment Test (CAD), and a history of moderate or severe exacerbations and hospitalizations (GOLD, 2019).

#### *1.1.1.6 Treatment and Management*

Effective COPD management can delay disease progression and reduce acute exacerbations, thereby improving the quality of life and reducing healthcare costs (Nguyen et al., 2009). Both pharmacological and non-pharmacological management strategies are crucial in COPD management. Non-pharmacological strategies improve health status and quality of life and reduce healthcare utilization by preventing the frequency and severity of COPD exacerbations (Suh, Mandal, & Hart, 2013). Various non-pharmacological interventions can be used to enhance COPD management. Smoking cessation is the most important factor that influences the natural history of COPD (GOLD, 2019). Pulmonary rehabilitation improves shortness of breath, health status, and exercise tolerance (GOLD, 2019). In addition, physical activity is beneficial for patients with COPD, and patients should repeatedly be encouraged to remain active (GOLD, 2019). The synergistic effects of multiple COPD interventions, such as pulmonary rehabilitation, oxygen supplementation, and physical activity can enhance COPD management.

Pharmacologic therapy is used to reduce symptoms, reduce the frequency and severity of exacerbations, and improve health status and exercise tolerance (GOLD, 2019). Although there are effective and inexpensive treatments for COPD, adherence rates are amongst the lowest of all chronic diseases, leading to avoidable adverse medical outcomes, costs, and reduced quality of life. Nonadherence in COPD is documented in the uptake of all therapies, including oxygen supplementation, physical rehabilitation, and medications; it contributes to rising rates of hospitalizations, deaths, and healthcare costs (Bender, 2016). Despite the fact that 24 million Americans have COPD, it has received considerably less attention in the adherence literature than asthma, diabetes, cardiovascular disease, and other chronic health conditions (Bender, 2016). Advances in technology have the potential to enhance both pharmacological and non-pharmacological interventions for COPD management.

### 1.1.2 Mobile Health (mHealth)

#### *1.1.2.1 Definition and context*

Decades ago, it would have cost tens of millions of dollars and required instruments that filled an entire room to produce the computational power of a smartphone (Markoff, 2011). This surge in computing power and mobile connectivity has led to the emergence of mHealth, which can transform the mode and quality of clinical research and healthcare (Steinhubl et al., 2015). mHealth is defined by the World Health Organization as the use of mobile wireless technologies for health (WHO, 2019). It also involves the use of the mobile phone's complex functionalities, including global positioning system (GPS) and Bluetooth technology. By using these technologies, smartphones can pair with medical devices, such as blood pressure monitors and pulse oximeters, to acquire and process health-related data. mHealth strategies hold great promise for enhancing treatment outcomes while mitigating healthcare costs (Hayes 2014; Vashist et al, 2016; WHO, 2019).

Researchers are now proposing mHealth applications for many health conditions such as dementia, autism, dysarthria, and Parkinson's disease (Zapata et al., 2015). Hayes et al. (2014) stated that mHealth could reduce physician visits, resource consumption, and emergency room visits. It is also suggested that smartphones can deliver effective interventions among various age groups and diseases (Joe et al., 2013; Juen et al., 2015; Zhang et al., 2013). mHealth offers an economy of scale by providing potential solutions for many problems and many types of patients. Moreover, researchers and clinicians will be able to obtain data from patients in real time. This information has the potential to enable enhanced healthcare delivery, improve quality of life, and reduce the burden on the healthcare system (Mutebi & Devroey, 2018).

#### *1.1.2.2 Access and Use of mHealth*

Before implementing mHealth solutions, it is important to understand the use of and access to mHealth. Duplaga et al. (2013) recruited 200 patients suffering from asthma and other chronic respiratory conditions to assess the acceptance of the use of mHealth applications. Participants responded to a questionnaire using a 5-point Likert scale. It was concluded that patients suffering from chronic respiratory conditions demonstrate higher levels of acceptance of mHealth applications such as appointment booking, prescription renewal, and access to information (laboratory test results, educational resources) than obtaining similar information via the traditional system of directly interacting with the medical system (communication with HCPs, disease monitoring) (Duplaga, 2013). This acceptance was associated with internet users, young age, high levels of education, and suffering from a disease for fewer than five years or suffering from a disease for 16 years or more (Duplaga, 2013).

Ramirez et al. (2016) found different results. They conducted a study to assess mobile phone and app usage among a culturally diverse patient population (244 participants), and to determine whether patients would be interested in using mHealth technology to manage their chronic diseases. The authors found that 91% percent of patients owned a mobile phone, with 76% of mobile phone owners reporting having a mobile phone with Internet capability. They also stated that although the majority of their primary care patients were of lower socioeconomic status, they used mobile phones with Internet and mobile app capabilities to a great extent.

To gain insight into the level of knowledge and experiences with mHealth of people with chronic lung diseases, Hofstede et al. (2014) completed a telephone survey of 400 people. The authors stated that although most asthma and COPD patients know of one or more mHealth applications, the actual use of these applications remains low (Hofstede et al., 2014). They recommended future studies to investigate patients' perceptions of facilitators and barriers to mHealth use in chronic lung diseases.

#### *1.1.2.3 mHealth in Newfoundland and Labrador*

mHealth interventions are particularly suitable in geographic locations with a relatively large proportion of rural residents, such as Newfoundland and Labrador (NL). Of the Atlantic Provinces, NL has the highest proportion of its population (60%) living in rural areas (Figure 1.2) (Simms & Greenwood, 2015). NL has unique challenges for effective and efficient healthcare delivery. It has been suggested that among patients with COPD, living in rural areas is associated with worse health status (Jackson et al., 2013; Abrams et al., 2013). Further, the authors suggest that the higher prevalence of COPD in rural areas could be linked to an increased proportion of older residents, shortage of healthcare providers (HCPs), underutilization of spirometry and pulmonary rehabilitation, and problems with access to medical care (Jackson et al., 2013; Abrams et al., 2013). However, Deitenbeck et al. (2018) promoted mHealth as being able to support equitable access to healthcare for rural residents (Deitenbeck et al., 2018). With its substantial remote and rural population, as well as a high proportion of commuters, NL may benefit from a model that increases patient outcomes using technology in the absence of convenient and regular access to healthcare.


**Figure 1.2:** Map of Newfoundland and Labrador.

### *1.1.2.4 mHealth for COPD management*

The current literature suggests the potential for smartphone integration in the management of COPD (Alwashmi et al., 2016; Noah et al., 2018), allowing mHealth to play a significant role in the management of modifiable risk factors. The application of a multifactorial mHealth intervention (e.g., COPD information, dose reminders, audio-visual material, motivational aspects, and training in inhalation techniques) resulted in an improvement in therapeutic adherence in patients with COPD (Leiva-Fernandez et al., 2014). Studies reported that pulmonary rehabilitation (Burkow et al., 2015) and physical activity interventions can be delivered remotely (Nguyen et al., 2009). Wang et al. (2014), stated that a mobile-phone-based system could provide an efficient home endurance exercise training program with improved exercise capacity, strengthened limb muscles, and a decrease in systemic inflammation in patients with COPD. Johnston et al. (2013) indicated that the smartphone-based collection of COPD symptom diaries allowed patients to identify exacerbation symptoms early on in the exacerbation, allowing for the opportunity for early intervention. And, Bender (2016) stated that COPD adherence may benefit from communication and advice delivered through mobile technology, along with a larger program of education, monitoring, and support. Telepharmacy, the delivery of pharmaceutical care via telecommunications to patients, can also be applied to educate patients suffering from COPD on how to improve medication use and adherence to treatment (Margolis et al., 2013).

Medical devices, such as spirometers and pulse oximeters, can obtain objective data that cannot be collected by smartphones alone. Recent advancements in technology allow for seamless integration between smartphones and medical devices. Various studies have paired medical devices with smartphone technology to assist in COPD management and detect exacerbations, such as electronic vests, heart rate monitors, pulse oximeters, and accelerometers

(Barberan-Garcia et al.., 2014; Beattie et al., 2014; Kelly et al., 2015; Kocsis et al., 2015; Nabhani-Gebara et al., 2014; Spina et al., 2015; Taylor et al., 2015; Tabak et al., 2014). However, these studies were focused on the technical effectiveness of these methods with limited involvement of patients during the design of these interventions. In addition, the studies gave limited attention to patient perceptions, usability, and satisfaction.

### 1.1.3 Human-Centered Design (HCD) of mHealth

#### *1.1.3.1 Definition and context*

The International Organization for Standardization (ISO) 9241-210 standard defines HCD as "an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" (ISO, 2010). The ISO uses the term HCD instead of user-centered design (UCD) to "address impacts on a number of stakeholders, not just those typically considered as users" (ISO, 2010). However, in practice, these terms are often used synonymously.

HCD has four defined activity phases: (1) identify the user and specify the context of use, (2) specify the user requirements, (3) produce design solutions to meet user requirements, and (4) evaluate design solutions against requirements. The process model of HCD as defined in ISO 9241-210 is illustrated in Figure 1.3.

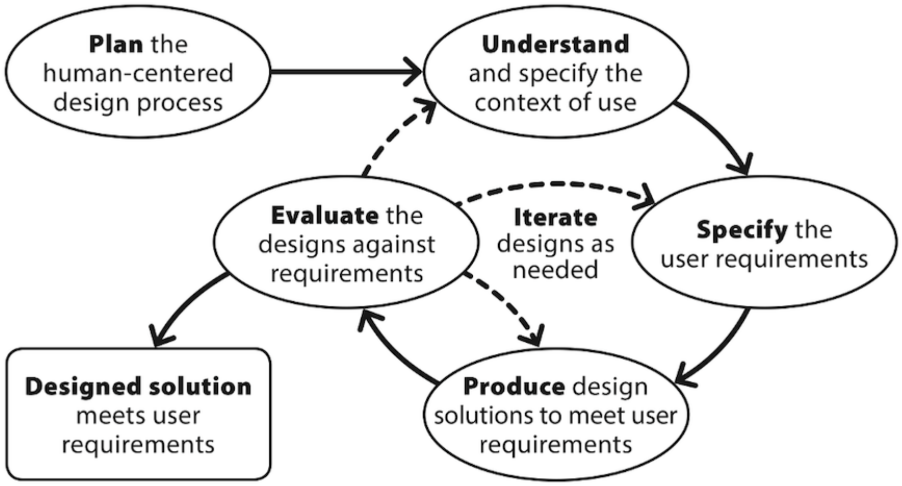



**Figure 1.3:** Human-centered design activity phases (ISO, 2010).

Understanding and specifying the context of mHealth along with specifying the user requirements can be accomplished by involving the users at the preliminary stages of development. Both quantitative and qualitative data are vital to understanding the user's needs and goals. Quantitative data can be used to assess the demographics, access, and use of mHealth, while qualitative data can be used to understand the patient's perceptions regarding mHealth. After the first iteration of the mHealth intervention is produced, usability testing can be employed to evaluate the designs against requirements.

#### *1.1.3.2 Importance of patient perspectives*

Researchers advocate developing an mHealth intervention with patients to meet their needs and facilitate successful uptake. When developing an mHealth intervention, Hopkins et al. (2016) encourage including insights from key users to potentially improve the process and the outcome of the intervention. And, testing mHealth interventions with patients revealed preferences and concerns unique to the tested population (Gray et al., 2016; Nelson et al., 2016; Sarkar et al., 2016). Triantafyllidis et al. (2015) stated that the limited uptake of mHealth adoption for remote monitoring is related to usage difficulties and low levels of patient satisfaction. They recommend focusing on the patient to assure the sustainable delivery of remote health monitoring services for heart failure. Developing a COPD mHealth intervention with insights from individuals with COPD will potentially improve the process and outcome of the mHealth intervention.

#### *1.1.3.3 Importance of healthcare provider perspectives*

Including patients and their healthcare providers (HCPs) is a fundamental step in the development of human-centered mHealth interventions (Korpershoek et al., 2018; Simpson et al., 2017). It ensures that the interface requirements of both users — patients and HCPs — are considered during mHealth development. Further, Bender (2014) suggests a collaborative care approach within teams composed of physicians, nurses, pharmacists, and patient advocates to lead to better care and higher patient adherence for complex and comorbid conditions. Also, other researchers recommend the involvement of a multidisciplinary team in mHealth interventions to develop tailored messages (Heffernan et al., 2016), address patient medication needs (DiDonato et al., 2015), enhance physical activity in patients with COPD (Vorrink et al, 2016), and to manage heart failure (Triantafyllidis et al., 2015), diabetes (Jo & Park, 2016), and cancer (Smith et al., 2015).

#### *1.1.3.4 Importance of usability testing*

The ISO defines usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use (ISO, 2018). Although this definition was published in 1998, it was updated in 2018 without any changes to the core concepts. The definition is broad and generalizable (Bevan et al., 2015; Goldberg et al., 2011).

mHealth involves the interaction between multiple user groups through a system, making the usability aspect of such systems crucial for the continuous, efficient, and satisfactory use of the application. Although patients have expressed interest in using technologies for self-management, current tools are not easy to use (Horton 2008; Sarkar et al., 2016). Difficulty in using an mHealth intervention may limit the user retention rate. A high dropout rate is one of the most significant barriers to mHealth adoption (Dorsey et al., 2017; Mayberry et al., 2017). The majority of mHealth app publishers (83%) have fewer than 10,000 users who have used their app at least once a month (Research2guidance, 2018). These numbers are discouraging, as according to a 2018 estimate, the average mHealth app costs $425,000 to develop (Research2guidance, 2018). By putting a more significant emphasis on usability, iterative improvements can reduce costs and enhance the long-term use and adoption of mHealth interventions (Ribeiro et al., 2016; Smith et al., 2016; Usability, n.d.a).

Researchers recommend frequent and iterative usability testing to respond to users' preferences and technical issues (Hattink et al., 2016; Nelson et al., 2016; Triantafyllidis et al., 2015). It is also important to ensure that errors in understanding or using the intervention are addressed before testing the intervention in an efficacy trial (Lyles et al., 2014). A systematic review investigated the usability evaluation processes described in 22 studies related to mHealth applications (Zapata et al., 2015). The results stress the importance of adapting health applications to users' needs (Zapata et al., 2015). Including insights from key users of mHealth has the potential to improve the process and the outcome of the intervention (Hopkins et al., 2016).

### 1.1.4 Mixed Methods Research (MMR)

#### *1.1.4.1 Definition and context*

MMR is gaining popularity and acceptance as a research methodology across disciplines around the world (Curry & Nunez-Smith, 2015). It draws from multiple scientific traditions and disciplinary backgrounds. MMR is defined as "the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches for the broad purposes of breadth and depth of understanding and corroboration" (Johnson, Onwuegbuzie, 2007, p.123). MMR combines two different perspectives: one drawn from closed-ended response data (quantitative) and one drawn from open-ended personal data (qualitative) (Creswell, 2015).

Although quantitative research has historically been the primary approach in health sciences research, many contemporary phenomena in health and healthcare are difficult, if not impossible, to measure using quantitative methods alone (Curry & Nunez-Smith, 2015). The goal of qualitative research is to produce a deep understanding of a phenomenon. It can also be used to generate a hypothesis regarding a phenomenon, its precursors, and its consequences (Curry et al., 2009). When the study phenomenon of interest is multifaceted and complex, a mixed methods approach is appropriate (Curry & Nunez-Smith, 2015). The National Institutes of Health best practices guideline and mixed methods researchers advise distinguishing the quantitative purpose, the qualitative research questions, and the mixed methods questions (Creswell et al., 2011). Consequently, MMR can capitalize on the strengths of both methods — the depth of qualitative and breadth of quantitative research. The resulting mixed data can be integrated to balance the strengths and limitations of either method to provide a more comprehensive understanding under potentially complementary sources of evidence (Curry & Nunez-Smith, 2015).

Understanding the principles and practices of integration is essential for leveraging the strengths of MMR. Fetters and Molina-Azorin (2017) defined integration as the linking of qualitative and quantitative approaches and dimensions to create a new whole or a more holistic understanding than can be achieved by either alone. Fetters et al. examined vital integration principles and practices in MMR (Fetters, Curry & Creswell, 2013). They provide approaches to integrating both research procedures and data in the design, methods, interpretation, and reporting dimensions of research. Table 1.1 provides the relevant dimensions of MMR integration and illustrates how researchers can integrate those dimensions. Additional information about MMR dimensions is provided elsewhere (Fetters & Molina-Azorin, 2017). Through increasingly sophisticated approaches, MMR is viewed as an opportunity to address the highly complex and compelling research problems facing researchers in the health and social sciences (Mertens, 2015). Investigation of novel mHealth technologies is an important example of a highly complex research challenge that can benefit from a systematic mixed methods approach.

**Table 1.1** Relevant dimensions of the mixed methods research integration, adapted from Fetters & Molina-Azorin, 2017.

| Integration dimensions | Mixed methods researchers integrate by: |
|---|---|
| Rationale dimension | Citing a rationale for conducting an integrated mixed methods research study (e.g., offsetting strengths and weaknesses, comparing, complementing or expanding, developing or building, and promoting social justice). |
| Study purpose, aims, and research questions | Composing an overarching mixed methods research purpose and stating qualitative, quantitative, and mixed methods aims or multiple mixed methods aims with quantitative aims and qualitative questions. |

| | |
|---|---|
| dimension | |
| Research design dimension | Scaffolding the work in core (e.g., convergent, exploratory sequential, and explanatory sequential), advanced (e.g., intervention, case study, evaluation, and participatory), or emergent designs. |
| Sampling dimension | Sampling through the type, through the relationship of the sources of the qualitative and quantitative data (e.g., identical sample, nested sample, separate samples, and multilevel samples), and through the timing (e.g., same or different periods for collection of the qualitative and quantitative data). |
| Data collection dimension | Collecting both types of data with an intent relative to the mixed methods research procedures (e.g., comparing, matching, diffracting, expanding, constructing a case, connecting, building, generating and validating a model, or embedding). |
| Data analysis dimension | Analyzing both types of data using intramethod analytics (e.g., analyzing each type of data within the respective qualitative and quantitative methods and core integration analytics), using one or more core mixed methods analysis approaches (e.g., by following a thread, spiraling, and back-and-forth exchanges), or employing advanced mixed methods analysis (e.g., qualitative to quantitative data transformation, quantitative to qualitative data transformation, creating joint displays, social network analysis, qualitative comparative analysis, repertory grid/other scale development techniques, geographic information systems mapping techniques, and iterative and longitudinal queries of the data). |
| Interpretation dimension | Interpreting the meaning of mixed findings (e.g., where there are related data and drawing metainferences or conclusions based on interpreting the qualitative and quantitative findings) and examining for the fit of the two types of data (e.g., confirmation, complementarity, expansion, or discordance). When the results conflict with each other, using procedures for handling the latter including reconciliation, initiation, bracketing, and exclusion. |

#### *1.1.4.2 Importance of Mixed Methods Research in Human-Centered Design*

Human-centered design is a complex phenomenon. It is challenging to investigate comprehensively using only quantitative methods or qualitative methods in isolation, so-called monomethod approaches (Carayon et al., 2015). The alternative to using a monomethod approach is using diverse methods to generate a complete picture and reveal hidden patterns and novel relationships between variables and concepts (Curry & Nunez-Smith, 2015). To identify and resolve design and usability issues, various researchers emphasize the importance of using multiple methods and sources of data (Nelson et al., 2016; Nitsch et al., 2016).

One application of MMR in HCD is the explanatory sequential design (Creswell, 2015). The intent of the explanatory sequential design is to begin with a quantitative strand and then conduct a second qualitative strand to explain the quantitative results (Creswell, 2015). An explanatory design is typically chosen when the team anticipates the quantitative measures will not be sufficient to address the research question. It may also be used when quantitative information is required to develop the sample for the qualitative phase (Curry & Nunez-Smith, 2015). Obtaining information from a diverse group may generate a more complete picture, reveal patterns that would otherwise go unnoticed, and may also cover novel relationships between variables and concepts (Curry & Nunez-Smith, 2015).

Despite the recognized and intuitive value of using mixed methods for mHealth usability testing, mixed methodologists have yet to articulate specific designs that guide the development and testing of mHealth interventions. Although many studies collect both quantitative and qualitative data to test usability (Alnasser et al., 2018; Beatty et al., 2018; and Sage et al., 2017), mHealth researchers could benefit from advances being made for integration in mixed methods studies (Fetters, Curry & Creswell, 2013; Creswell & Clark, 2017). A core MMR study design that is attractive for usability testing is the convergent design (Creswell & Clark, 2017). This is also called by some authors a concurrent parallel study (Tashakkori, Teddlie, & Teddlie, 1998) or, historically, a concurrent triangulation design (Creswell et al., 2003). The convergent mixed methods design features the collection and analysis of both types of data and then the merging of the data for the final interpretation (Creswell, 2015).

## 1.2 Knowledge gap and research questions

### 1.2.1 Knowledge gap in the effectiveness of mHealth in COPD management

Little is understood about the effectiveness of mHealth in COPD management. Initially, I was going to create an mHealth intervention and test it to understand the effectiveness of mHealth in COPD management. But before developing the mHealth intervention, I started with a systematic review and meta-analysis of existing mHealth interventions for COPD management (Chapter 2). The effectiveness of mHealth interventions has receiving increased scholarly attention in recent years; however, the vast majority of this research is focused on the effectiveness of specific mHealth interventions. A thorough review of the literature is necessary to understand the gaps and challenges in the current use of mHealth in COPD management. It will inform the design of future smartphone apps that aim to limit COPD exacerbations.

Instead of developing an mHealth intervention and pilot testing it, which is similar to existing studies, I decided to explore the barriers and facilitators of adopting mHealth for COPD management. In addition, I wanted to understand the requirements of an mHealth intervention for COPD management by taking into account the needs and requirements of patients with COPD as well as similar or different thoughts of their HCPs

### 1.2.2 Knowledge gap in understanding the perceptions of users of mHealth in COPD management

The findings of the systematic review shifted my focus from developing and testing an mHealth intervention to understanding the process of developing an mHealth intervention. Studies paid limited attention to patient perceptions, usability, and satisfaction. Therefore, gaps may exist in terms of development and usability testing for mHealth interventions for COPD management.

At the time of the study initiation, I could not find any study that assessed the perceptions of individuals with COPD and their HCPs regarding the use of mHealth for COPD management. Patient and HCP perspectives towards using mHealth for COPD management are relatively unexplored (Dennison at el. 2013; Korpershoek et al., 2018). Korpershoek et al., however, did provide some insight into the perceptions of patients with COPD and their HCPs towards using mHealth for COPD management, such as the importance of personalizing the mHealth intervention and making it usable. They also recommended including a larger sample of HCPs with more mHealth experience in future studies (Korpershoek et al., 2018). A recent meta-analysis on the remote monitoring of patients with COPD concluded that some interventions may prove to be promising in changing clinical outcomes in the future, but there are still large gaps in the evidence base (Noah et al., 2018). Noah et al. (2018) suggest that adding a qualitative component would give researchers insight into which elements best engage and motivate patients and HCPs.

For my study, with the intent to improve the success of mHealth interventions in COPD management, I included patients with COPD and their HCPs to better understand the role of mHealth in COPD management. I used international guidelines, such as ISO, and MMR design to better understand why a particular mHealth component might be successful and how patients use mHealth interventions in the long term. Lessons learned will bridge the knowledge gap of barriers and facilitators for mHealth uptake in COPD management. The study will also highlight the important features of mHealth that have the potential to meet the needs of patients with COPD and their HCPs.

### 1.2.3 Knowledge gap in a Mixed Methods Research framework suitable for usability testing of mHealth

Despite the recognized and intuitive value of using mixed methods for mHealth usability testing, mixed methods researchers have yet to articulate specific designs that guide the development and testing of mHealth interventions. Although many studies collect both quantitative and qualitative data to test usability (Alnasser et al., 2018; Beatty et al., 2018; and Sage et al., 2017), mHealth researchers could benefit from advances being made for integration in mixed methods studies (Creswell & Clark, 2017; Fetters, Curry & Creswell, 2013). A systematic review of published MMR health services studies found that only one-third of articles provided justifications for an MMR design (Wisdom et al., 2012). In chapter 6, I provide a novel MMR framework suitable for usability testing of mHealth interventions.

### 1.2.4 Research questions

There are several areas in which this research adds to the current state of knowledge. The overarching question of this thesis is:

- How to apply the human-centered design process when developing an mHealth intervention for COPD management?

A combination of quantitative, qualitative, and mixed methods research approaches was used to answer the following research questions:

- Based on the existing literature, what is the association between mHealth interventions and the management of COPD exacerbations? (chapter 2)
- What are the potential facilitators and barriers that might influence healthcare providers of patients with COPD regarding the use of mHealth in COPD management? (chapter 3)

- What are the potential facilitators and barriers that might influence patients with COPD regarding the use of mHealth in COPD management? (chapter 4)
- What are the demographics of patients with COPD, and how do they use and access smartphones? (chapter 4)
- How can an mHealth intervention for COPD management be developed that takes into account the needs and requirements of patients with COPD and their HCPs? (chapter 5)
- What is the most suitable MMR framework for generating unique insights into the usability of mHealth? (chapter 6)

This research, while focused on individuals with COPD, adds to the current understanding of how mHealth can be used to manage chronic diseases in general. The outcome of this thesis is expected to provide insight into how patient and HCP involvement in design and evaluation can practicably be performed and inform the development of mHealth interventions that are effective, efficient, easy to use, and provide a high level of user satisfaction.

## 1.3 Thesis organization

This thesis is organized in a manuscript format, including five journal articles as chapters. Each chapter of the thesis text was prepared as a "stand alone" document describing the published work or work prepared for publication. All components were integrated into a logical progression from chapter to chapter, forming a unified and consistent report of the research undertaking. Due to the inherent nature of the manuscript-based dissertation style, there is some unavoidable repetition in some of the literature review and methods sections. Table 1.2 shows the journal papers completed during the research and also demonstrates the objectives of each chapter.

**Table 1.2:** Journal articles and objectives of each chapter

| Papers as chapters | Objectives |
|---|---|
| Chapter 2: The Effect of Smartphone Interventions on Patients with Chronic Obstructive Pulmonary Disease Exacerbations: A Systematic Review and Meta-Analysis | To summarize and quantify the association between mHealth interventions and management of COPD exacerbations through a comprehensive systematic review and meta-analysis. |
| Chapter 3: Perceptions of Healthcare Providers Regarding a Mobile Health Intervention to Manage Chronic Obstructive Pulmonary Disease: a Qualitative Study | To explore the potential facilitators and barriers among HCPs regarding the use of mHealth interventions for COPD management. |
| Chapter 4: Perceptions of patients with COPD regarding a Mobile Health intervention to manage COPD: a Mixed Methods Study | To describe the demographics, use, and access to smartphones.<br>To explore and develop an understanding of potential facilitators and barriers that might influence patients with COPD using mHealth interventions for COPD management. |
| Chapter 5: Features of a Mobile Health Intervention to Manage Chronic Obstructive Pulmonary Disease: a Qualitative Study | To explore the potential features that can be included in an mHealth intervention for COPD management. |
| Chapter 6: The Iterative Convergent Design for Mobile Health Usability Testing: Mixed Methods Approach | To provide a novel framework for generating unique insights into multifaceted phenomena impacting mHealth usability. |

To answer these questions, this research follows the ISO HCD activity phases that were discussed in section 1.1.2.1 (illustrated in Figure 1.4). Chapter 2 provides a systematic review of the literature. This review is necessary to understand the gaps and challenges in the current use of smartphones in COPD management. Chapters 3 and 4 explore the perceptions of patients with COPD and their HCPs regarding the use of mHealth for COPD management. These perceptions include the facilitators and barriers of using an mHealth intervention for COPD management. After interviewing HCPs (chapter 3), the findings informed the development of the interview prompts for patients (chapter 4). Chapter 5 includes potential features that can be included in an mHealth intervention for COPD management. It elaborates on features required by patients and their HCPs. Both HCPs and patients stressed the importance of usability to improve the uptake of mHealth interventions. As a result, chapter 6 provides a novel mixed methods framework that can be used to enhance the usability of potential mHealth interventions. The proposed framework is demonstrated using different case studies.

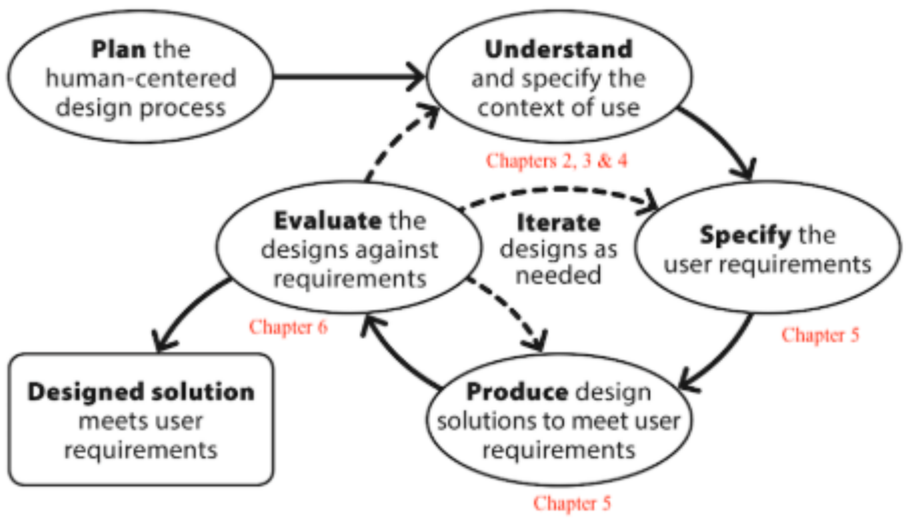



**Figure 1.4:** Human-centered design activity phases and the associated thesis chapters.

## 1.4 References


Abrams, T. E., Vaughan-Sarrazin, M., Fan, V. S., & Kaboli, P. J. (2011). Geographic isolation and the risk for chronic obstructive pulmonary disease–related mortality: A cohort study. Annals of internal medicine, 155(2), 80-86.

Alnasser, A., Kyle, J., Alkhalifah, A., & Marais, D. (2018). Relationship Between Evidence Requirements, User Expectations, and Actual Experiences: Usability Evaluation of the Twazon Arabic Weight Loss App. JMIR human factors, 5(2), e16.

Alwashmi, M., Hawboldt, J., Davis, E., Marra, C., Gamble, J. M., & Ashour, W. A. (2016). The Effect of Smartphone Interventions on Patients With Chronic Obstructive Pulmonary Disease Exacerbations: A Systematic Review and Meta-Analysis. JMIR mHealth and uHealth, 4(3).

Barberan-Garcia, A., Vogiatzis, I., Solberg, H. S., Vilaró, J., Rodriguez, D. A., Garåsen, H. M., ... & NEXES Consortium. (2014). Effects and barriers to deployment of telehealth wellness programs for chronic patients across 3 European countries. Respiratory medicine, 108(4), 628-637.

Beattie, M. P., Zheng, H., Nugent, C., & McCullagh, P. (2014). COPD lifestyle support through self-management (CALS). In Bioinformatics and Biomedicine (BIBM), 2014 IEEE International Conference on (pp. 1-7). IEEE.

Beatty, A. L., Magnusson, S. L., Fortney, J. C., Sayre, G. G., & Whooley, M. A. (2018). VA fitheart, a mobile app for cardiac rehabilitation: usability study. JMIR human factors, 5(1), e3.

Bender, B. G. (2014). Nonadherence in chronic obstructive pulmonary disease patients: what do we know and what should we do next?. Current opinion in pulmonary medicine, 20(2), 132-137.

Bevan, N., Carter, J., & Harker, S. (2015). ISO 9241-11 revised: What have we learnt about usability since 1998?. In International Conference on Human-Computer Interaction (pp. 143-151). Springer, Cham.

Burkow, T. M., Vognild, L. K., Johnsen, E., Risberg, M. J., Bratvold, A., Breivik, E., ... & Hjalmarsen, A. (2015). Comprehensive pulmonary rehabilitation in home-based online groups: a mixed method pilot study in COPD. BMC research notes, 8(1), 766.

Canadian Chronic Disease Surveillance System. (2018). Asthma and Chronic Obstructive Pulmonary Disease (COPD) in Canada, 2018. Retrieved from https://www.Canada.ca/en/public-health/services/publications/diseases-conditions/asthma-chronic-obstructive-pulmonary-disease-Canada-2018.html

Canadian Institute for Health Information. (2008). Health indicators. Retrieved from https://secure.cihi.ca/free_products/HealthIndicators2008_ENGweb.pdf

Canadian Institute for Health Information (CIHI). Health Indicators URL: https://secure.cihi.ca/free_products/HealthIndicators2008_ENGweb.pdf

Carayon, P., Kianfar, S., Li, Y., Xie, A., Alyousef, B., & Wooldridge, A. (2015). A systematic review of mixed methods research on human factors and ergonomics in health care. Applied ergonomics, 51, 291-321.

Creswell, J. W., & Clark, V. L. P. (2017). Designing and conducting mixed methods research. Sage publications.

Creswell, J. W., Klassen, A. C., Plano Clark, V. L., & Smith, K. C. (2011). Best practices for mixed methods research in the health sciences. Bethesda (Maryland): National Institutes of Health, 2013, 541-545.

Creswell, J. W., Plano Clark, V. L., Gutmann, M. L., & Hanson, W. E. (2003). Advanced mixed methods research designs. Handbook of mixed methods in social and behavioral research, 209, 240.

Creswell, J. W. (2015). A concise introduction to mixed methods research. Los Angeles: SAGE.

Criner, G. J., Bourbeau, J., Diekemper, R. L., Ouellette, D. R., Goodridge, D., Hernandez, P., ... & Celli, B. R. (2015). Prevention of acute exacerbations of COPD: American college of chest physicians and Canadian thoracic society guideline. Chest, 147(4), 894-942.

Cruz, J., Brooks, D., & Marques, A. (2014). Home telemonitoring in COPD: a systematic review of methodologies and patients' adherence. International journal of medical informatics, 83(4), 249-263.

Curry, L., & Nunez-Smith, M. (2015). Mixed methods in health sciences research: a practical primer.

Curry, L. A., Nembhard, I. M., & Bradley, E. H. (2009). Qualitative and mixed methods provide unique contributions to outcomes research. Circulation, 119(10), 1442-1452.

Decramer, M., Janssens, W., & Miravitlles, M. (2012). Chronic obstructive pulmonary disease. *The Lancet, 379*(9823), 1341-1351.

Deitenbeck, B., Qureshi, S., & Xiong, J. (2018). The Role of mHealth for Equitable Access to Healthcare for Rural Residents.

Dennison, L., Morrison, L., Conway, G., & Yardley, L. (2013). Opportunities and challenges for smartphone applications in supporting health behavior change: qualitative study. Journal of medical Internet research, 15(4), e86.

DiDonato, K. L., Liu, Y., Lindsey, C. C., Hartwig, D. M., & Stoner, S. C. (2015). Community pharmacy patient perceptions of a pharmacy-initiated mobile technology app to improve adherence. International Journal of Pharmacy Practice, 23(5), 309-319.

Ding, H., Moodley, Y., Kanagasingam, Y., & Karunanithi, M. (2012, August). A mobile-health system to manage chronic obstructive pulmonary disease patients at home. In 2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society (pp. 2178-2181). IEEE.

Dorsey, E. R., McConnell, M. V., Shaw, S. Y., Trister, A. D., & Friend, S. H. (2017). The use of smartphones for health research. Academic Medicine, 92(2), 157-160.

Duplaga, M. (2013). The acceptance of e-health solutions among patients with chronic respiratory conditions. Telemedicine and e-Health, 19(9), 683-691.

Elbehairy, A. F., Webb, K. A., Neder, J. A., & O'Donnell, D. E. (2013). Should mild COPD be treated? evidence for early pharmacological intervention. *Drugs, 73*(18), 1991-2001.

Evans, J., Chen, Y., Camp, P., Bowie, D., and McRae, L. (2014). Estimating the prevalence of COPD in Canada: Reported diagnosis versus measured airflow obstruction.

Fetters, M. D., & Molina-Azorin, J. F. (2017). The Journal of Mixed Methods Research starts a new decade: The mixed methods research integration trilogy and its dimensions.

Fetters, M. D., Curry, L. A., & Creswell, J. W. (2013). Achieving integration in mixed methods designs—principles and practices. Health services research, 48(6pt2), 2134-2156.

Global Initiative for Chronic Obstructive Lung Disease. (2019). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease. Retrieved from http://www.goldcopd.com/uploads/users/files/GOLD_Report_2014_Oct30.pdf

Goldberg, L., Lide, B., Lowry, S., Massett, H. A., O'Connell, T., Preece, J., ... & Shneiderman, B. (2011). Usability and accessibility in consumer health informatics: current trends and future challenges. American journal of preventive medicine, 40(5), S187-S197.

Gray, C. S., Khan, A. I., Kuluski, K., McKillop, I., Sharpe, S., Bierman, A. S., ... & Cott, C. (2016). Improving patient experience and primary care quality for patients with complex chronic disease using the electronic patient-reported outcomes tool: adopting qualitative methods into a user-centered design approach. JMIR research protocols, 5(1), e28.

Hattink, B., Droes, R. M., Sikkes, S., Oostra, E., & Lemstra, A. W. (2016). Evaluation of the Digital Alzheimer Center: testing usability and usefulness of an online portal for patients with dementia and their carers. JMIR research protocols, 5(3), e144.

Han, M. K., Muellerova, H., Curran-Everett, D., Dransfield, M. T., Washko, G. R., Regan, E. A., ... & Jones, P. W. (2013). GOLD 2011 disease severity classification in COPDGene: a prospective cohort study. The lancet Respiratory medicine, 1(1), 43-50.

Hayes, D., Markus, H., Leslie, R., & Topol, E. (2014). Personalized medicine: risk prediction, targeted therapies and mobile health technology. BMC Medicine, 12(1), 37. http://dx.doi.org/10.1186/1741-7015-12-37

Hofstede, J., de Bie, J., Van Wijngaarden, B., & Heijmans, M. (2014). Knowledge, use and attitude toward eHealth among patients with chronic lung diseases. International journal of medical informatics, 83(12), 967-974.

Hogg, J. C. (2004). Pathophysiology of airflow limitation in chronic obstructive pulmonary disease. The Lancet, 364(9435), 709-721.

Hopkins, I. G., Dunn, K., Bourgeois, F., Rogers, J., & Chiang, V. W. (2016, June). From development to implementation—A smartphone and email-based discharge follow-up program for pediatric patients after hospital discharge. In Healthcare (Vol. 4, No. 2, pp. 109-115). Elsevier.

Horton, K. (2008). The use of telecare for people with chronic obstructive pulmonary disease: implications for management. Journal of nursing management, 16(2), 173-180.

International Organization for Standardization. (2010). 9241-210 2010. Ergonomics of human system interaction-part 210: Human-centred design for interactive systems. Standard. International Organization for Standardization, Tech. rep. International.

International Organization for Standardization. (2018). Ergonomics of human-system interaction - part 11: Usability: Definitions and concepts

Jackson, B. E., Coultas, D. B., Suzuki, S., Singh, K. P., & Bae, S. (2013). Rural-Urban Disparities in Quality of Life Among Patients With COPD. The Journal of Rural Health, 29(s1), s62-s69.

Jo, S., & Park, H. (2016). Development and evaluation of a smartphone application for managing gestational diabetes mellitus. Healthcare informatics research, 22(1), 11-21.

Joe, J., & Demiris, G. (2013). Older adults and mobile phones for health: a review. Journal of biomedical informatics, 46(5), 947-954.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a Definition of Mixed Methods Research. Journal of Mixed Methods Research,1(2), 112-133. doi:10.1177/1558689806298224

Johnston, K., Grimmer-Somers, K., Young, M., Antic, R., & Frith, P. (2012). Which chronic obstructive pulmonary disease care recommendations have low implementation and why? A pilot study. BMC research notes, 5(1), 652.

Jones, P. W. (2009). Health status and the spiral of decline. COPD: Journal of Chronic Obstructive Pulmonary Disease, 6(1), 59-63.

Juen, J., Cheng, Q., & Schatz, B. (2015). A natural walking monitor for pulmonary patients using mobile phones. IEEE Journal of biomedical and health informatics, 19(4), 1399-1405.

Kelly, D., Donnelly, S., & Caulfield, B. (2015, August). Smartphone derived movement profiles to detect changes in health status in COPD patients-A preliminary investigation. In 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) (pp. 462-465). IEEE.

Kim, V., & Criner, G. J. (2013). Chronic bronchitis and chronic obstructive pulmonary disease. American journal of respiratory and critical care medicine, 187(3), 228-237.

Kocsis, O., Vasilopoulou, M., Tsopanoglou, A., Papaioannou, A., & Vogiatzis, I. (2015, November). Telemonitoring system for home rehabilitation of patients with COPD. In 2015 E-Health and Bioengineering Conference (EHB) (pp. 1-4). IEEE.

Korpershoek, Y. J., Vervoort, S. C., Trappenburg, J. C., & Schuurmans, M. J. (2018). Perceptions of patients with chronic obstructive pulmonary disease and their health care providers towards using mHealth for self-management of exacerbations: a qualitative study. BMC health services research, 18(1), 757.

Krug, S. (2014). Don’t Make Me Think, Revisited: A Common Sense Approach to Web Usability (Voices That Matter).

Lareau, S. C., & Hodder, R. (2012). Teaching inhaler use in chronic obstructive pulmonary disease patients. Journal of the American Academy of Nurse Practitioners, 24(2), 113-120.

Leiva-Fernández, J., Leiva-Fernández, F., García-Ruiz, A., Prados-Torres, D., & Barnestein-Fonseca, P. (2014). Efficacy of a multifactorial intervention on therapeutic adherence in patients with chronic obstructive pulmonary disease (COPD): a randomized controlled trial. BMC pulmonary medicine, 14(1), 70.

Lin, H. -., Murray, M., Cohen, T., Colijn, C., & Ezzati, M. (2008). Effects of smoking and solid-fuel use on COPD, lung cancer, and tuberculosis in China: A time-based, multiple risk factor, modelling study. *The Lancet, 372*(9648), 1473-1483.

Lopez, A. D., Shibuya, K., Rao, C., Mathers, C. D., Hansell, A. L., Held, L. S., ... & Buist, S. (2006). Chronic obstructive pulmonary disease: current burden and future projections. European Respiratory Journal, 27(2), 397-412.

Lyles, C. R., Sarkar, U., & Osborn, C. Y. (2014). Getting a technology-based diabetes intervention ready for prime time: a review of usability testing studies. Current diabetes reports, 14(10), 534.

Margolis, A., Young, H., Lis, J., Schuna, A., & Sorkness, C. A. (2013). A telepharmacy intervention to improve inhaler adherence in veterans with chronic obstructive pulmonary disease. American Journal of Health-System Pharmacy, 70(21), 1875-1876.

Markoff, J. (2011). The iPad in your hand: As fast as a supercomputer of yore. New York Times, 9.

Matkovic, Z., Huerta, A., Soler, N., Domingo, R., Gabarrús, A., Torres, A., & Miravitlles, M. (2012). Predictors of adverse outcome in patients hospitalised for exacerbation of chronic obstructive pulmonary disease. Respiration, 84(1), 17-26.Mayberry, L. S., Mulvaney, S. A., Johnson, K. B., & Osborn, C. Y. (2017). The MEssaging for Diabetes intervention reduced barriers to medication adherence among low-income, diverse adults with type 2. Journal of diabetes science and technology, 11(1), 92-99.

Mertens, D. M. (2015). Mixed methods and wicked problems.

Miller, D., Gray, C. S., Kuluski, K., & Cott, C. (2015). Patient-centered care and patient-reported measures: let's look before we leap. The Patient-Patient-Centered Outcomes Research, 8(4), 293-299.

Miravitlles, M., García-Polo, C., Domenech, A., Villegas, G., Conget, F., & de la Roza, C. (2013). Clinical outcomes and cost analysis of exacerbations in chronic obstructive pulmonary disease. Lung, 191(5), 523-530.

Mittmann, N., Kuramoto, L., Seung, S. J., Haddon, J. M., Bradley-Kennedy, C., & FitzGerald, J. M. (2008). The cost of moderate and severe COPD exacerbations to the Canadian healthcare system. *Respiratory Medicine, 102*(3), 413-421.

Mutebi, I., & Devroey, D. (2018). Perceptions on mobile health in the primary healthcare setting in Belgium. mHealth, 4.

Nabhani-Gebara, S., Kayyali, R., Philip, N., Pierscionek, B., Sobnath, D., Kaimakamis, E., ... & D'Arcy, S. (2014, November). WELCOME project: What do stakeholders want? In depth analysis of COPD patients, carers and healthcare professional views. In 2014 4th International Conference on Wireless Mobile Communication and Healthcare-Transforming Healthcare Through Innovations in Mobile and Wireless Technologies (MOBIHEALTH) (pp. 365-368). IEEE.

Najafzadeh, M., Marra, C. A., Lynd, L. D., Sadatsafavi, M., FitzGerald, J. M., McManus, B., & Sin, D. (2012). Future impact of various interventions on the burden of COPD in Canada: a dynamic population model. PloS one, 7(10), e46746.

Nelson, L. A., Mayberry, L. S., Wallston, K., Kripalani, S., Bergner, E. M., & Osborn, C. Y. (2016). Development and usability of REACH: a tailored theory-based text messaging intervention for disadvantaged adults with type 2 diabetes. JMIR human factors, 3(2), e23.

Nguyen, H. Q., Gill, D. P., Wolpin, S., Steele, B. G., & Benditt, J. O. (2009). Pilot study of a cell phone-based exercise persistence intervention post-rehabilitation for COPD. International journal of chronic obstructive pulmonary disease, 4, 301.

Nitsch, M., Dimopoulos, C. N., Flaschberger, E., Saffran, K., Kruger, J. F., Garlock, L., ... & Jones, M. (2016). A guided online and mobile self-help program for individuals with eating disorders: An iterative engagement and usability study. Journal of medical Internet research, 18(1), e7.

Noah, B., Keller, M. S., Mosadeghi, S., Stein, L., Johl, S., Delshad, S., ... & Spiegel, B. M. (2018). Impact of remote patient monitoring on clinical outcomes: an updated meta-analysis of randomized controlled trials. NPJ Digital Medicine, 1(1), 20172.

O'donnell, D. E., Hernandez, P., Kaplan, A., Aaron, S., Bourbeau, J., Marciniuk, D., ... & Maltais, F. (2008). Canadian Thoracic Society recommendations for management of chronic obstructive pulmonary disease–2008 update–highlights for primary care. Canadian Respiratory Journal, 15(Suppl A), 1A-8A.

Pahal, P., & Sharma, S. (2019). Emphysema. In StatPearls [Internet]. StatPearls Publishing.

Public Health Agency of Canada. (2018). Report from the Canadian Chronic Disease Surveillance System: Asthma and Chronic Obstructive Pulmonary Disease (COPD) in Canada, 2018. [online] Available at: http://publications.gc.ca/collections/collection_2018/aspc-phac/HP35-90-2018-eng.pdf [Accessed 13 Sep. 2019].

Public Health Agency of Canada. (2012). Fast facts about chronic obstructive pulmonary disease (COPD) 2011. Retrieved from http://www.phac-aspc.gc.ca/cd-mc/publications/copd-mpoc/ff-rr-2011-eng.php

Public Health Agency of Canada. (2007). Life and breath: Respiratory disease in Canada. Retrieved from http://www.phac-aspc.gc.ca/publicat/2007/lbrdc-vsmrc/index-eng.php

Ramirez, V., Johnson, E., Gonzalez, C., Ramirez, V., Rubino, B., & Rossetti, G. (2016). Assessing the use of mobile health technology by patients: an observational study in primary care clinics. JMIR mHealth and uHealth, 4(2).

Research2guidance. (2018). mHealth economics - how mHealth app publishers are monetizing their apps URL: https://research2guidance.com/product/mHealth-economics-how-mHealth-app-publishers-are-monetizing-their-apps/ [accessed 2019-04-05]

Ribeiro, N., Moreira, L., Barros, A., Almeida, A. M., & Santos-Silva, F. (2016). Guidelines for a cancer prevention smartphone application: a mixed-methods study. International journal of medical informatics, 94, 134-142.

Sage, A., Roberts, C., Geryk, L., Sleath, B., Tate, D., & Carpenter, D. (2017). A Self-Regulation Theory–Based Asthma Management Mobile App for Adolescents: A Usability Assessment. JMIR human factors, 4(1), e5.

Sarkar, U., Gourley, G. I., Lyles, C. R., Tieu, L., Clarity, C., Newmark, L., ... & Bates, D. W. (2016). Usability of commercially available mobile applications for diverse patients. Journal of general internal medicine, 31(12), 1417-1426.

Shah, C. Velardo, O. J. Gibson, H. Rutter, A. Farmer and L. Tarassenko. (2014). Personalized alerts for patients with COPD using pulse oximetry and symptom scores," 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Chicago, IL, 2014, pp. 3164-3167.

Simms, A., & Greenwood, R. (2015). Newfoundland and Labrador. State of Rural Canada Report, 73.

Simpson, A. J., Honkoop, P. J., Kennington, E., Snoeck-Stroband, J. B., Smith, I., East, J., ... & Usmani, O. (2017). Perspectives of patients and healthcare professionals on mHealth for asthma self-management. European Respiratory Journal, 49(5), 1601966.

Smith, S. A., Claridy, M. D., Whitehead, M. S., Sheats, J. Q., Yoo, W., Alema-Mensah, E. A., ... & Coughlin, S. S. (2015). Lifestyle modification experiences of African American breast cancer survivors: a needs assessment. JMIR cancer, 1(2), e9.

Spina, G., Casale, P., Albert, P. S., Alison, J., Garcia-Aymerich, J., Costello, R. W., ... & Singh, S. J. (2015). Identifying physical activity profiles in COPD patients using topic models. IEEE journal of biomedical and health informatics, 19(5), 1567-1576.

Statistics Canada. (2011). Leading causes of death, by sex (both sexes). Retrieved from: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/hlth36a-eng.htm

Statistics Canada. (2013). Chronic obstructive pulmonary disease in Canadians, 2009 to 2011. Retrieved from http://www.statcan.gc.ca/pub/82-625-x/2012001/article/11709-eng.htm

Statistics Canada. (2018). Leading causes of death, by sex URL: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/hlth36a-eng.htm

Statistics Canada. (2019). Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1310009619

Steinhubl, S. R., Muse, E. D., & Topol, E. J. (2015). The emerging field of mobile health. Science translational medicine, 7(283), 283rv3-283rv3.

Suh, E. , Mandal, S., & Hart, N. (2013). Admission prevention in COPD: Non-pharmacological management. *BMC Medicine, 11*(1)

Tabak, M., Op den Akker, H., & Hermens, H. (2014). Motivational cues as real-time feedback for changing daily activity behavior of patients with COPD. Patient education and counseling, 94(3), 372-378.

Tashakkori, A., Teddlie, C., & Teddlie, C. B. (1998). Mixed methodology: Combining qualitative and quantitative approaches (Vol. 46). Sage.

Taylor, J., Coates, E., Wessels, B., Mountain, G., & Hawley, M. S. (2015). Implementing solutions to improve and expand telehealth adoption: participatory action research in four community healthcare settings. BMC health services research, 15(1), 529.

Toledo, P. D., Jiménez, S., Pozo, F. D., Roca Torrent, J., Alonso, A., & Hernandez, C. (2006). Telemedicine experience for chronic care in COPD. IEEE Transactions On Information Technology in Biomedicine, 2006, vol. 10, núm. 3, p. 567-573.

The Conference Board of Canada. (2012). Cost risk analysis for chronic lung disease in Canada Retrieved from http://www.conferenceboard.ca/e-library/abstract.aspx?did=4585

Theriault, L., Gregory, H., Goldfarb, D., Stonebridge, C., Bounajm, F. (2012). Cost risk analysis for chronic lung disease in Canada. [ ] *The Conference Board of Canada,*

Triantafyllidis, A., Velardo, C., Chantler, T., Shah, S. A., Paton, C., Khorshidi, R., ... & SUPPORT-HF Investigators. (2015). A personalised mobile-based home monitoring system for heart failure: the SUPPORT-HF study. International journal of medical informatics, 84(10), 743-753.

US Department of Health and Human Services. (2014). The health consequences of smoking—50 years of progress: a report of the Surgeon General.

Usability.gov. Benefits of user-centered design  URL: https://www.usability.gov/what-and-why/benefits-of-ucd.html [accessed 2019-04-05]

Vashist, S., Luppa, P., Yeo, L., Ozcan, A., & Luong, J. (2015). Emerging Technologies for Next-Generation Point-of-Care Testing. Trends In Biotechnology, 33(11), 692-705. http://dx.doi.org/10.1016/j.tibtech.2015.09.001

Vorrink, S. N., Kort, H. S., Troosters, T., & Lammers, J. W. J. (2016). A mobile phone app to stimulate daily physical activity in patients with chronic obstructive pulmonary disease: development, feasibility, and pilot studies. JMIR mHealth and uHealth, 4(1), e11.

Vos, T., Flaxman, A. D., Naghavi, M., Lozano, R., Michaud, C., Ezzati, M., . . . Murray, C. J. (2012). Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries

1990-2010: A systematic analysis for the global burden of disease study 2010. *The Lancet, 380*(9859), 2163-219

Wang, C. H., Chou, P. C., Joa, W. C., Chen, L. F., Sheng, T. F., Ho, S. C., ... & Kuo, H. P. (2014). Mobile-phone-based home exercise training program decreases systemic inflammation in COPD: a pilot study. BMC pulmonary medicine, 14(1), 142.

Wisdom, J. P., Cavaleri, M. A., Onwuegbuzie, A. J., & Green, C. A. (2011). Methodological Reporting in Qualitative, Quantitative, and Mixed Methods Health Services Research Articles. Health Services Research,47(2), 721-745. doi:10.1111/j.1475-6773.2011.01344.x

World Health Organization. (2019). Projections of mortality and causes of death, 2016 to 2060. Retrieved from https://www.who.int/healthinfo/global_burden_disease/projections/en/

World Health Organization. (2019). WHO guideline: recommendations on digital interventions for health system strengthening.

Zapata, B. C., Fernández-Alemán, J. L., Idri, A., & Toval, A. (2015). Empirical studies on usability of mHealth apps: a systematic literature review. Journal of medical systems, 39(2), 1.

Zhang J, Song YL, Bai CX. MIOTIC study: A prospective, multicenter, randomized study to evaluate the long-term efficacy of mobile phone-based internet of things in the management of patients with stable COPD. Int J Chron Obstruct Pulmon Dis. 2013;8:433-438. doi: 10.2147/COPD.S50205 [doi].

# Chapter 2: The Effect of Smartphone Interventions on Patients with Chronic Obstructive Pulmonary Disease Exacerbations: A Systematic Review and Meta-Analysis.

## Preface

A version of this chapter has been published in the Journal of Medical Internet Research (JMIR) - mHealth and uHealth: Alwashmi, M., Hawboldt, J., Davis, E., Marra, C., Gamble, J. M., & Ashour, W. A. (2016). The effect of smartphone interventions on patients with chronic obstructive pulmonary disease exacerbations: a systematic review and meta-analysis. JMIR mHealth and uHealth, 4(3), e105. This publication has been cited by several authors and organizations, including the World Health Organization and the European Respiratory Society. As the primary author, I reviewed the literature and analyzed the data. I completed the first version of the manuscript and further revised according to the suggestions of co-authors and reviewers. Dr. Hawboldt and Dr. Davis helped to identify the research topic and scope. Dr. Carlo Marra and Dr. John-Michael Gamble reviewed the manuscript and provided revision suggestions. Dr. Waseem AbuAshour helped to screen the articles and extract data for analysis.


## Abstract

**Background:** The prevalence and mortality rates of chronic obstructive pulmonary disease (COPD) are increasing worldwide. Therefore, COPD remains a major public health problem. There is a growing interest in the use of smartphone technology for health promotion and disease management interventions. However, the effectiveness of smartphones in reducing the number of patients having a COPD exacerbation is poorly understood.

**Objective:** To summarize and quantify the association between smartphone interventions and COPD exacerbations through a comprehensive systematic review and meta-analysis.

**Methods:** A comprehensive search strategy was conducted across relevant databases (PubMed, Embase, Cochrane, CINHA, PsycINFO, and the Cochrane Library Medline) from inception to October 2015. We included studies that assessed the use of smartphone interventions in the reduction of COPD exacerbations compared with usual care. Full-text studies were excluded if the investigators did not use a smartphone device or did not report on COPD exacerbations. Observational studies, abstracts, and reviews were also excluded. Two reviewers extracted the data and conducted a risk of bias assessment using the US Preventive Services Task Force quality rating criteria. A random effects model was used to meta-analyze the results from included studies. Pooled odds ratios were used to measure the effectiveness of smartphone interventions on COPD exacerbations. Heterogeneity was measured using the $I^2$ statistic.

**Results:** Of the 245 unique citations screened, 6 studies were included in the qualitative synthesis. Studies were relatively small with less than 100 participants in each study (range 30 to 99) and follow-up ranged from 4-9 months. The mean age was 70.5 years (SD 5.6) and 74% (281/380) were male. The studies varied in terms of country, type of smartphone intervention, frequency of data collection from the participants, and the feedback strategy. Three studies were included in the meta-analysis. The overall assessment of potential bias of the studies that were included in the meta-analysis was "Good" for one study and "Fair" for 2 studies. The pooled random effects odds ratio of patients having an exacerbation was 0.20 in patients using a smartphone intervention (95% CI 0.07-0.62), a reduction of 80% for smartphone interventions compared with usual care. However, there was moderate heterogeneity across the included studies ($I^2$=59%).

**Conclusion:** Although current literature on the role of smartphones in reducing COPD exacerbations is limited, findings from our review suggest that smartphones are useful in reducing the number of patients having a COPD exacerbation. Nevertheless, using smartphones require synergistic strategies to achieve the desired outcome. These results should be interpreted with caution due to the heterogeneity among the studies. Researchers should focus on conducting rigorous studies with adequately powered sample sizes to determine the validity and clinical utility of smartphone interventions in the management of COPD.

## 2.1 Introduction

Chronic obstructive pulmonary disease (COPD) refers to a group of lung diseases that includes chronic bronchitis and emphysema. Often, the occurrence of COPD is associated with smoking (GOLD, 2015). The Global initiative for chronic Obstructive Lung Disease (GOLD) defines COPD as follows:

> *Chronic obstructive pulmonary disease (COPD), a common preventable and treatable disease, is characterized by persistent airflow limitation that is usually progressive and associated with an enhanced chronic inflammatory response in the airways and the lung to noxious particles or gases. Exacerbations and comorbidities contribute to the overall severity in individual patients (GOLD, 2015).*

The prevalence and mortality rates of COPD are increasing worldwide. Therefore, COPD remains a major public health problem. One of the major effects of COPD is a reduced physical activity level in the affected patients (Watz et al., 2009). Although COPD is a preventable and treatable condition, it is the fourth leading cause of death in Canada (Statistics Canada, 2016).

GOLD defines a COPD exacerbation as an acute event characterized by a worsening of the patient's respiratory symptoms that is beyond normal day-to-day variations and leads to a change in medication (GOLD, 2015). An acute exacerbation of COPD has detrimental effects on lung function, health-related quality of life, and exercise capacity (Suh et al., 2013). According to the Canadian Institute for Health Information, COPD now accounts for the highest rate of hospital admission and readmission among major chronic illnesses in Canada (Canadian Institute for Health Information, 2008). The Conference Board of Canada has stated that the combined direct and indirect costs of COPD will increase from just under $4 billion in 2010 to roughly $9.5 billion by 2030, an increase of 140% (Najafzadeh et al., 2012). Dynamic modeling has shown that any intervention that can reduce the number of exacerbations in a population will have a substantial impact on morbidity and costs of COPD (Najafzadeh et al., 2012, Theriault et al., 2012).

Current advances in smartphones have allowed for opportunities to provide effective health promotion and disease management interventions. Several published studies indicate that smartphones can deliver effective interventions among various age groups and diseases (Joe & Demiris, 2013; Juen et al., 2015; Zhang et al., 2013; Thakkar et al., 2016). Moreover, interventions delivered via a smartphone may empower patients to play a more active role in managing their health (Juen et al., 2015).

Recent improvements in smartphones suggest a potential for integration into COPD management. Effective COPD management could delay disease progression, reduce acute exacerbations, and improve quality of life (Spina et al., 2013). Wang et al stated that a mobile phone–based system could provide an efficient home endurance exercise training program to improve exercise capacity, strengthen limb muscles and decrease systemic inflammation in COPD patients (Wang et al., 2014). Another study indicated that smartphone-based collection of COPD symptom diaries allows patients to identify exacerbation symptoms at an early stage allowing for the opportunity for early intervention (Wang et al., 2014; Johnston et al., 2013).

A thorough review of the literature is necessary to understand the gaps and challenges in the current use of smartphones in COPD management. It will inform the design of future smartphone apps that aim to limit COPD exacerbations. Therefore, we conducted a systematic review and meta-analysis to answer the following question:

**In patients diagnosed with COPD, will using smartphone interventions, compared with not using smartphone interventions, reduce the number of patients that have at least one exacerbation?**

## 2.2 Methods

### 2.2.1 Eligibility Criteria

We included randomized controlled trials and quasi-randomized studies that used smartphone interventions in patients with COPD. A smartphone was defined as a mobile phone that performs many of the functions of a computer, typically having a touchscreen interface, Internet access, and an operating system capable of running downloaded applications. Some smartphone interventions can also include the use of medical devices that transfer data to the smartphone or a Web-based platform for monitoring and analysis. Studies define COPD exacerbations differently due to the lack of a universally accepted objective definition of a COPD exacerbation. Some investigators define COPD based on drug use, reported symptoms, or emergency admission. As a result, we based our definition of exacerbation according to the GOLD criteria:

> *COPD exacerbation is an acute event characterized by a worsening of the patient's respiratory symptoms that is beyond normal day-to-day variations and leads to a change in medication (GOLD, 2015).*

Studies that included additional medical conditions as well as COPD were retained if the outcomes specific to the COPD group were reported separately. All English and non-English language studies identified during the search were considered. Non-English language studies included an English abstract. The abstract was sufficient to apply the eligibility criteria. Observational studies, abstracts, and reviews were excluded. Studies without a control group were also excluded. Smartphones are carried everywhere, have constant Internet connections, and are used as communication devices. Therefore, studies that used only a tablet or Web-based intervention and not specifically a smartphone intervention were excluded.

### 2.2.2 Search Strategy

A comprehensive literature search was conducted in consultation with a librarian with experience in conducting systematic reviews. The literature search was run from the inception of each database until October 14, 2015 using the methods recommended by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). Five electronic databases: PubMed, Embase, Cochrane, CINHA, PsycINFO, and the Cochrane Library were searched for published article that studied the effect of smartphone interventions on COPD exacerbations. The references of all included studies were examined for relevant articles. The researchers used key search terms to identify potential studies (see Table 2.1).

**Table 2.1:** Search terms for the systematic review.

| Search lines | Search terms |
|---|---|
| Line 1 | (((((((("obstructive lung disease"[Title/Abstract]) OR copd[Title/Abstract]) OR coad[Title/Abstract]) OR "chronic obstructive pulmonary disease"[Title/Abstract]) OR "chronic obstructive lung disease"[Title/Abstract]) OR "chronic obstructive airway* disease"[Title/Abstract])) OR ((((("Lung Diseases, Obstructive"[Mesh]) OR "Pulmonary Disease, Chronic Obstructive"[Mesh]) OR "COPD, Severe Early-Onset"[Supplementary Concept]) OR "Pulmonary Emphysema"[Mesh]) OR "Bronchitis, Chronic"[Mesh]))) |
| 2. AND | ((((((((((((((((((((((((((("mobile phone"[Title/Abstract]) OR "smart phone"[Title/Abstract]) OR smartphone[Title/Abstract]) OR "cell phone"[Title/Abstract]) OR "personal digital assistant"[Title/Abstract]) OR PDA[Title/Abstract]) OR microcomputer[Title/Abstract]) OR blackberry[Title/Abstract]) OR nokia[Title/Abstract]) OR samsung[Title/Abstract]) OR "i phone"[Title/Abstract]) OR iPhone[Title/Abstract]) OR symbian[Title/Abstract]) OR windows[Title/Abstract]) OR INQ[Title/Abstract]) OR iPad[Title/Abstract]) OR "i pad"[Title/Abstract]) OR ipod[Title/Abstract]) OR "i pod"[Title/Abstract]) OR mhealth[Title/Abstract]) OR "mobile health"[Title/Abstract]) OR "m health"[Title/Abstract]) OR "m-health"[Title/Abstract]) OR app[Title/Abstract]) OR HTC[Title/Abstract]) OR samsung[Title/Abstract]) OR apps[Title/Abstract])) OR (((("Cell Phones"[Mesh]) OR "Computers, Handheld"[Mesh]) OR "Text Messaging"[Mesh]) OR "Telemedicine"[Mesh]))) |
| 3. AND | (("Disease Progression"[Mesh]) OR exacerbation[Title/Abstract]) |

### 2.2.3 Study Screening

Two authors (MA and WA) screened titles and abstracts for each unique citation. The screening process included removing duplicates and excluding studies that were not related to COPD or telemonitoring. The remaining full-text studies were then assessed for eligibility. Full-text studies were excluded if the investigators did not use a smartphone device or did not report on COPD exacerbations. The reviewers also included studies that reported the rate of COPD exacerbations in the intervention group but were not able to report the rate in the control group.

The remaining studies were assessed for potential bias according to the US Preventive Services Task Force (USPSTF) quality rating criteria (Chou et al., 2010). Review of bias assessments were completed independently by 2 reviewers (MA and WA). Any disagreements arising between the reviewers were resolved by discussion until a consensus was achieved.

### 2.2.4 Data Extraction and Synthesis

Data were extracted regarding the study design, study procedure, intervention, population demographics, and number of patients having an exacerbation. Two reviewers (MA and WA) extracted data independently. Data from 3 studies were pooled using Review Manager version 5.3 (The Nordic Cochrane Centre, The Cochrane Collaboration, Copenhagen). A random effects model was used to pool results from the included studies and calculate a summary odds ratio to measure the independent effect of smartphone interventions on COPD exacerbations. We tested for variance across studies using the chi-square test and measured the degree of heterogeneity using the $I^2$ statistic.

## 2.3 Results

### 2.3.1 Overview

The study selection process is outlined in Figure 2.1. The search process yielded 245 records, providing 201 citations after duplicates were removed. Of these, 6 studies met the eligibility criteria (Nguyen et al., 2008; Liu et al., 2008; Halpin et al., 2011; Pedone et al., 2013; Jehn et al., 2013; Tabak et al., 2014).

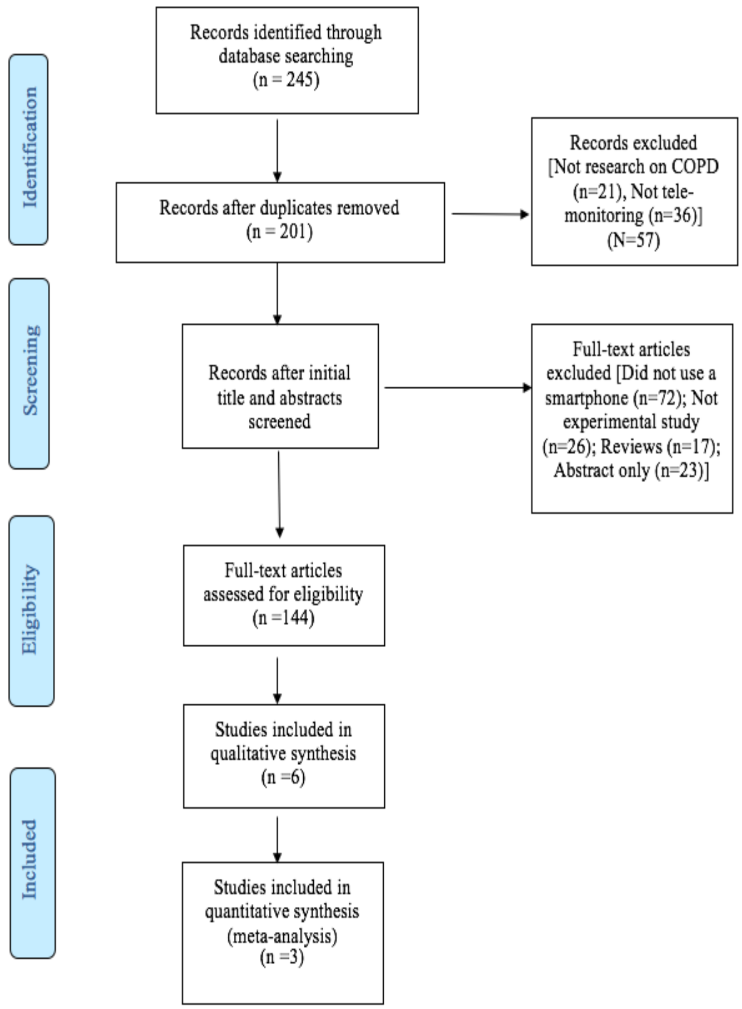



**Figure 2.1:** Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram of search results and study selection. COPD: chronic obstructive pulmonary disease.

### 2.3.2 Qualitative Analysis

Six studies were included in the qualitative analysis. Table 2.2 provides characteristics of the 6 included research studies (Nguyen et al., 2008; Liu et al., 2008; Halpin et al., 2011; Pedone et al., 2013; Jehn et al., 2013; Tabak et al., 2014). All the articles were published after 2008. All of the studies were conducted on relatively small samples, less than 100 participants each. Some research studies specified the COPD severity stage according to the GOLD guidelines (Liu et al., 2008; Pedone et al., 2013; Jehn et al., 2013), whereas other studies included patients in all COPD stages (Nguyen et al., 2008; Halpin et al., 2011; Tabak et al., 2014). Furthermore, patients were required to be free from COPD exacerbations for either at least 3 weeks (Pedone et al., 2013) or one month (Nguyen et al., 2008; Halpin et al., 2011; Jehn et al., 2013; Tabak et al., 2014) to be included in the research studies. Studies included older participants; the mean age was 70.5 years (SD of 5.6). All studies had a large percentage of male participants (mean 74%).

Table 2.3 provides characteristics of the methodology used in the research studies (Nguyen et al., 2008; Liu et al., 2008; Halpin et al., 2011; Pedone et al., 2013; Jehn et al., 2013; Tabak et al., 2014). The studies were conducted in various countries around the world. Five of the six included studies were randomized controlled trials (Nguyen et al., 2008; Liu et al., 2008; Halpin et al., 2011; Pedone et al., 2013; Jehn et al., 2013; Tabak et al., 2014), and one study used a quasi- experimental design (Liu et al., 2008). Postintervention follow-up assessment for the included studies ranged between 4 months and 9 months. The smartphone in each study was primarily used to collect data about the daily symptoms of the patient. As a complement to the smartphone intervention, education about self-management and exercise training (Nguyen et al., 2008; Liu et al., 2008; Tabak et al., 2014) was also used in some studies. Participants used the smart phone to report physical activity level (Tabak et al., 2014), daily symptoms (Nguyen et al., 2008; Liu et al., 2008; Halpin et al., 2011; Pedone et al., 2013; Jehn et al., 2013; Tabak et al., 2014), and heart rate and oxygen saturation (Pedone et al., 2013). One study provided a Web portal to enable patients to treat exacerbations themselves (Tabak et al., 2014). All studies compared a smartphone intervention versus usual care as the control group, except one study. Tabak et al. provided both the intervention and control groups with a smartphone, but only the intervention group received automated phone calls to remind the participants about the treatment regimen and to ensure that they had sufficient medications (Tabak et al., 2014). All studies provided participants with a smartphone but did not report other incentives to participate in the study.

The frequency of collecting data from participants was different within each study. Symptoms and objective measurements such as spirometry and pulse oximetry were collected on a daily basis. Alternatively, physical activity data were collected weekly. The investigators assessed collected data on a daily basis. When an exacerbation was detected, patients were contacted to confirm the exacerbation. One study used an automated feedback mechanism that advised to start medication in case of an exacerbation (Jehn et al., 2013).

**Table 2.2:** Characteristics of studies using smartphone interventions with COPD patients.

| First author, (year) | COPD[a] stage | $FEV_1$[b], mean (SD), % predicted | | Participant age (years), mean (SD), | | Male sex, % | | Sample size (analyzed) | | No. of patients having an exacerbation | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IG[c] | CG[d] | IG | CG | IG | CG | IG | CG | IG | CG |
| Tabak, (2014) | All stages | 48.7 (16.7) | 56.4 (10.6) | 65.2 (9.0) | 67.9 (5.7) | 57% | 68% | 15 (10) | 15 (2) | 33 | N/R[e] |
| Pedone, (2013) | II or III | 52.5 (14.9) | 55.4 (15.8) | 74.1 (6.4) | 75.4 (6.7) | 72% | 63% | 50 (39) | 49 (49) | 9 | 15 |
| Jehn, (2013) | II-IV | 50.2 (15) | 52.6 (17.5) | 64.1 (10.9) | 69.1 (9.2) | 81% | 73% | 32 (32) | 30 (30) | 7 | 22 |
| Halpin, (2011) | All stages | 48 (4) | 54 (3) | 68.5 (1.5) | 70.2 (1.6) | 74% | 73% | 40 (39) | 39 (38) | 23 | 26 |
| Nguyen, (2008) | All stages | 49.0 (16.8) | 50.3 (17.6) | 68.0 (8.3) | 70.9 (8.6) | 61% | 55% | 26 (20) | 24 (19) | 10 | N/R |
| Liu, (2008) | II or III | 45.2(3.2) | 46 (2.8) | 71.4 (1.7) | 72.8 (1.3) | 100% | 100% | 30 (24) | 30 (24) | 2 | 10 |

[a]COPD: Chronic Obstructive Pulmonary Disease.

[b]$FEV_1$: Forced Expiratory Volume in one second.

[c]IG: Intervention Group.

[d]CG: Control Group.

[e]N/R: not reported.

**Table 2.3:** Summary of the methodology in studies using smartphone interventions with COPD patients.

| First author, (year) | Design (Follow-up) Country | Intervention (Frequency) | Control |
|---|---|---|---|
| Tabak, (2014) | RCT[a] (9 months) Netherlands | Short respiratory symptoms questionnaires, exercise program and self-management recommendations on the Web portal (Daily);<br>Activity coach via an accelerometer and a smartphone (4days/week). | Usual care |
| Pedone, (2013) | RCT (9 months) Italy | Heart rate, physical activity, near-body temperature, and galvanic skin response via wristband coupled with a smartphone (Every 3 hours);<br>Oxygen saturation levels via a portable pulse oximeter (Every 3 hours).<br>A physician contacted participants to provide feedback in case of abnormal readings (Daily). | Usual care |
| Jehn, (2013) | RCT (9 months) Germany | COPD Assessment Test on the smartphone (Daily);<br>Lung Function Tests via a portable spirometer (Daily).<br>Six-minute walk test measured by accelerometer (Weekly).<br>A study nurse contacted the participant to remind them about entering data (Daily). | Usual care |
| Halpin, (2011) | RCT (4 months) United Kingdom | The Exacerbations of Chronic Pulmonary Disease Tool (EXACT) questionnaire on the smartphone (Daily);<br>Automated phone calls to remind patients about the treatment regimen and ensure they have sufficient medication (Weekly). | EXACT questionnaire on the smartphone |

| | | | |
|---|---|---|---|
| Nguyen, (2008) | RCT (6 months) United States | Exercise training program via smartphone (Daily); Short respiratory symptoms questionnaires on the smartphone (Daily). A study nurse contacted the participant to remind them about entering data and provide feedback (Daily). | Usual care |
| Liu, (2008) | **NRCT**[b] (9 months) Taiwan | Home-based endurance exercise training program via smartphone (Daily); Short respiratory symptoms questionnaires on the smartphone (Daily). | Usual care |

[a]RCT: Randomized Controlled Trial.

[b]NRCT: Nonrandomized Controlled Trial.

### 2.3.3 Quantitative Analysis

Three studies were included in the meta- analysis (Liu et al., 2008; Pedone et al., 2013; Jehn et al., 2013). Two studies were excluded because they did not report the number of patients having an exacerbation in the control group (Nguyen et al., 2008; Tabak et al., 2014), and another study provided a smartphone intervention to both the intervention and control groups (Nguyen et al., 2008). The follow-up period for all 3 studies was 9 months. All 3 studies reported that participants receiving smartphone interventions experienced a reduction in COPD exacerbations (Liu et al., 2008; Pedone et al., 2013; Jehn et al., 2013). Two studies used intention-to-treat analysis (Pedone et al., 2013; Jehn et al., 2013) and one study used per-protocol analysis (Pedone et al., 2013). The pooled odds ratio of patients having an exacerbation was 0.20 in the patients using a smartphone intervention (95% CI 0.07-0.62) compared with those receiving usual care. The meta-analysis of COPD exacerbations indicates a reduction of 80% for smartphone interventions compared with usual care. There was moderate heterogeneity across the studies that were included in the meta-analysis ($\chi^2$=4.9, P=.08, $I^2$=59%) (Tabak et al., 2014). The results are outlined in Figure 2.2.

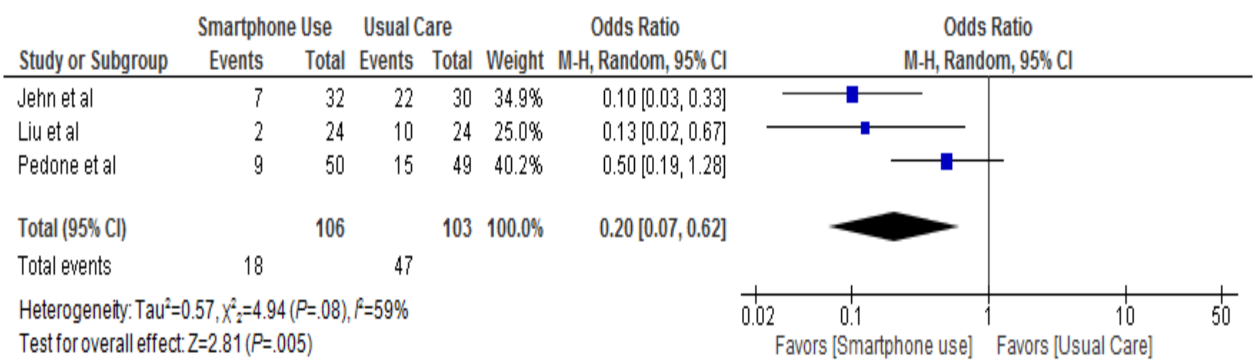



**Figure 2.2:** Effects of smartphone interventions on the number of patients having a COPD exacerbation.COPD: Chronic Obstructive Pulmonary Disease.

### 2.3.4 Risk of Bias

A summary of the assessment of potential bias of studies selected for inclusion, using USPSTF Quality Rating Criteria, can be found in Table 2.4 The overall assessment of the studies that were included in the meta-analysis was Good (Jehn et al., 2013) and Fair (Liu et al., 2008; Pedone et al., 2013). It was not possible to assess for publication bias via funnel plot asymmetry due to the low number of studies included in the meta-analysis (Higgins & Green, 2011).

**Table 2.4:** Assessment of potential bias of studies selected for inclusion using USPSTF Quality Rating Criteria (Chou & Dana, 2016).

| Study | Assembly of comparable groups | Maintenance of comparable groups | No important differential loss to follow-up or overall high loss to follow-up | Measurements: equal, reliable, valid (includes masking of outcome assessment) | Clear definition of interventions | All-important outcome considered | Analysis: adjustment for potential confounders | Overall assessed quality |
|---|---|---|---|---|---|---|---|---|
| Nguyen (2008) | Good | Fair | Good | Fair | Good | Good | Poor | Fair |
| Halpin (2011) | Good | Good | Fair | Fair | Poor | Fair | Fair | Fair |
| Pedone (2013) | Fair | Good | Good | Fair | Good | Fair | Good | Fair |
| Liu (2008) | Fair | Good | Fair | Fair | Good | Good | Fair | Fair |
| Jehn et (2013) | Fair | Good | Good | Fair | Good | Good | Good | Good |
| Tabak (2014) | Poor | Fair | Poor | Fair | Good | Good | Fair | Poor |

## 2.4 Discussion

### 2.4.1 Principal Results

The existing literature indicated that there is a potential for smartphone interventions in reducing the frequency of COPD exacerbations. Although most COPD patients were older than 65 years, they were able to use smartphones to monitor their symptoms. Rates of COPD exacerbations among participants receiving a smartphone intervention during the trials proved to be less compared with the participants not receiving a smartphone intervention. The main objective for using a smartphone is early identification of COPD exacerbations. Early identification allows the patient and health care team to intervene successfully, thus improving the management of COPD and reducing COPD exacerbations. As stated previously, Najafzadeh et al. indicate that any intervention that reduces the number of exacerbations has a substantial impact on morbidity and costs of COPD (Najafzadeh et al., 2012).

Our finding that smartphones could be useful in reducing COPD exacerbations replicates the findings of 3 cohort studies. Jarad and Sund (2011) coupled a smartphone with a portable spirometer and indicated that it reduced the number of hospitalizations for COPD exacerbations. Johnston et al (2013) showed that smartphone-based collection of COPD symptom diaries allows patients to identify exacerbation symptoms early on in the exacerbation allowing for early intervention. Furthermore, Ding et al conducted a cohort study of a mobile phone–based home monitoring system and demonstrated the potential of smartphones in early identification of COPD exacerbations (2014). Thakkar et al (2016) conducted a systematic review and stated that mobile phone text messaging approximately doubles the odds of medication adherence in patients with chronic diseases. Smartphones can incorporate text-messaging interventions in addition to various interventions that include, but are not limited to, surveys, reminders, and the ability to be paired with medical devices.

### 2.4.2 Risk of Bias

Although the included studies reported promising results, there was moderate heterogeneity ($I^2$=59%) across studies that were included in the meta-analysis. Liu et al (2008) did not randomize patients to the intervention while the other 2 studies conducted randomized controlled trials (Pedone et al., 2013; Jehn et al., 2013). The studies also varied in location, COPD severity, smartphone intervention, frequency of data collection from the participants, and the feedback strategy.

In some studies, the smartphone intervention was combined with different variations of symptoms diaries, physiological monitoring, and educational elements directed at patients. Patients used the smartphone to report daily symptoms (Liu et al., 2008; Jehn et al., 2013) or deliver a home-based exercise training program (Pedone et al., 2013). In addition, investigators coupled the smartphone with various medical devices to measure physical activity levels (Pedone et al., 2013; Jehn et al., 2013), heart rate and oxygen saturation (Pedone et al., 2013), and pulmonary function tests (Liu et al., 2008). Each intervention, patient education or use of medical devices, could itself account for the differences between groups. Additionally, one researcher (Pedone et al., 2013) had a physician to contact participants to provide feedback regarding abnormal readings. Therefore, researchers should be cautious when interpreting the synergistic effect from the combination of these interventions.

The frequency of data collection from participants and feedback strategy also differed between the studies. Liu et al collected data from participants every day (Liu et al., 2008). The data was reviewed weekly and feedback was given to participants during their three-month follow up visits. Jehn et al collected data from participants every day and physicians reviewed the data daily; however, the feedback strategy to patients was unclear (Jehn et al., 2013). Pedone et al collected data more frequently than other studies due to the use of the wristband and portable pulse oximeter (Pedone et al., 2013). Unusual data were flagged and physicians assessed the data on a daily basis. Then, physicians contacted the participants to assess for a COPD exacerbation and suggest an intervention.

Only 2 studies reported on metrics related to user experience (Nguyen et al., 2008; Tabak et al., 2014). Nugyen et al conducted semistructured interviews with participants at the end of the study (Nguyen et al., 2008). Participants were asked to provide feedback on what aspects of the program were most or least helpful for managing their dyspnea and how the program could have been done differently to support self-management. On the other hand, Tabak et al used the Client Satisfaction Questionnaire to measure user satisfaction (Tabak et al., 2014). Unfortunately, we were unable to combine the usability results due to the differences in the methods used to measure user experience.

The frequency of data collection from the participant was also dependent on the type of data being collected. Symptoms were collected daily while exercise progress was assessed weekly. Collecting data from participants frequently could yield more accurate data; nevertheless, it must not compromise the participant's adherence to the intervention. There are many factors that could have caused the reduction in COPD exacerbation. Early detection of symptoms and timely treatment could be possible by the use of smartphones or due to phone contact by the research team. Currently, we are uncertain whether the reduction in the number of patients having an exacerbation is caused by the smartphone intervention or merely due to bias among the studies. Additional investigations are required before large-scale implementation of smartphone interventions.

### 2.4.3 Limitations

Aside from the methodological heterogeneity among studies, there are several limitations with this systematic review. There are a limited number of studies using smartphones in the management of COPD exacerbations, each with relatively small samples, less than 100 participants each. A comprehensive search strategy was used, but studies utilizing smartphones in the management of COPD exacerbations that are still in progress or provided only an abstract were excluded. All investigators provided a smartphone to participants. This could have caused highly motivated participants who are familiar with smartphones to contribute data. Another limitation is that studies did not clearly define exacerbations (recognized and unrecognized) and how to identify it (e.g., drug use, reported symptoms, and emergency admission). Tabak used a self-management Web portal to measure exacerbations, which could have yielded many false positive results. The review favored smartphone interventions across all studies, thus overall findings do indicate that smartphone interventions may reduce the number of patients having COPD exacerbations across a wide variety of contexts.

### 2.4.4 Implications for Future Research

Implementing a mixed methods research design to investigate the validity and clinical utility of smartphone interventions could help to understand why a particular component is successful and how patients will use smartphone interventions for a long-term. There is limited research regarding smartphone interventions among COPD patients. Although the studies in this review have a small sample size and a relatively short follow-up period, current literature supports the potential of smartphones in reducing COPD exacerbations. There is a need for more studies evaluating smartphone interventions, including studies using smartphones as the main intervention. This will assist in determining whether smartphones can be effective in the management of COPD. Investigators should include participants with different stages of COPD severity and age spans to minimize the risk of bias and enhance the generalizability of the study results.

## 2.5 Conclusion

Although the current literature on the role of smartphones in reducing COPD exacerbations is limited, our results suggest that smartphone interventions may reduce COPD exacerbations. Nevertheless, using smartphones require synergistic strategies, such as providing feedback based on both subjective and objective data, to achieve the desired outcome. The results should be interpreted with caution due to the heterogeneity among the studies, risk of small study bias, and limitations in study quality. Researchers should focus on conducting rigorous randomized controlled trial (RCT) studies with adequately powered sample sizes to determine the validity and clinical utility of smartphone interventions in the management of COPD.

## 2.6 References


Canadian Institute for Health Information, (2008). Health Indicators. Retrieved from URL: https://secure.cihi.ca/free_products/HealthIndicators2008_ENGweb.pdf

Chou R & Dana T. (2010). U.S. Preventive Services Task Force Quality Rating Criteria. Agency For Healthcare Research And Quality (US). Retrieved from URL: http://www.ncbi.nlm.nih.gov/books/NBK47515/

Ding, H., Karunanithi, M., Kanagasingam, Y., Vignarajan, J., & Moodley, Y. (2014). A pilot study of a mobile-phone-based home monitoring system to assist in remote interventions in cases of acute exacerbation of COPD. Journal of Telemedicine and Telecare, 20(3), 128-134.

Global Initiative for Chronic Obstructive Pulmonary Disease, (2015). Global Strategy for the Diagnosis, Management, and Prevention of COPD. Retrieved from URL: http://www.goldcopd.it/materiale/2015/GOLD_Report_2015.pdf

Halpin, D. M., Laing-Morton, T., Spedding, S., Levy, M. L., Coyle, P., Lewis, J., ... & Marno, P. (2011). A randomised controlled trial of the effect of automated interactive calling combined with a health risk forecast on frequency and severity of exacerbations of COPD assessed clinically and using EXACT PRO. Primary Care Respiratory Journal, 20(3), 324.

Higgins, J. P., & Green, S. (Eds.). (2011). Cochrane handbook for systematic reviews of interventions (Vol. 4). John Wiley & Sons.

Jarad, N. A., & Sund, Z. M. (2011). Telemonitoring in chronic obstructive airway disease and adult patients with cystic fibrosis. Journal of telemedicine and telecare, 17(3), 127-132.

Jehn, M., Donaldson, G., Kiran, B., Liebers, U., Mueller, K., Scherer, D., ... & Witt, C. (2013). Tele-monitoring reduces exacerbation of COPD in the context of climate change–a randomized controlled trial. Environmental Health, 12(1), 99.

Joe, J., & Demiris, G. (2013). Older adults and mobile phones for health: a review. Journal of biomedical informatics, 46(5), 947-954.

Johnston, C. L., Maxwell, L. J., Boyle, E., Maguire, G. P., & Alison, J. A. (2013). Improving chronic lung disease management in rural and remote Australia: the Breathe Easy Walk Easy programme. Respirology, 18(1), 161-169.

Juen, J., Cheng, Q., & Schatz, B. (2015). A natural walking monitor for pulmonary patients using mobile phones. IEEE Journal of biomedical and health informatics, 19(4), 1399-1405.

Liu, W. T., Wang, C. H., Lin, H. C., Lin, S. M., Lee, K. Y., Lo, Y. L., ... & Kuo, H. P. (2008). Efficacy of a cell phone-based exercise programme for COPD. European Respiratory Journal, 32(3), 651-659.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Annals of internal medicine, 151(4), 264-269.

Najafzadeh, M., Marra, C. A., Lynd, L. D., Sadatsafavi, M., FitzGerald, J. M., McManus, B., & Sin, D. (2012). Future impact of various interventions on the burden of COPD in Canada: a dynamic population model. PloS one, 7(10), e46746.

Nguyen, H., Donesky-Cuenco, D., Wolpin, S., Reinke, L., Benditt, J., Paul, S., & Carrieri-Kohlman, V. (2008). Randomized controlled trial of an internet-based versus face-to-face dyspnea self-management program for patients with chronic obstructive pulmonary disease: pilot study. Journal of medical Internet research, 10(2), e9.

Nguyen, H. Q., Gill, D. P., Wolpin, S., Steele, B. G., & Benditt, J. O. (2009). Pilot study of a cell phone-based exercise persistence intervention post-rehabilitation for COPD. International journal of chronic obstructive pulmonary disease, 4, 301.

Oxford Dictioinaries. Smartphone URL: http://www.oxforddictionaries.com/definition/English/smartphone

Pedone, C., Chiurco, D., Scarlata, S., & Incalzi, R. A. (2013). Efficacy of multiparametric telemonitoring on respiratory outcomes in elderly people with COPD: a randomized controlled trial. BMC health services research, 13(1), 82.

Review Manager (RevMan) Computer program, (2014). The Nordic Cochrane Centre. Copenhagen: The Cochrane Collaboration. RevMan 5 download and installation URL: http://tech.cochrane.org/revman/download

Spina, G., Huang, G., Vaes, A., Spruit, M., & Amft, O. (2013, September). COPDTrainer: a smartphone-based motion rehabilitation training system with real-time acoustic feedback. In Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing (pp. 597-606). ACM.

Statistics Canada, (2016). Leading causes of death, by sex URL: http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/hlth36a-eng.htm

Suh, E. S., Mandal, S., & Hart, N. (2013). Admission prevention in COPD: non-pharmacological management. BMC medicine, 11(1), 247.

Tabak, M., Brusse-Keizer, M., van der Valk, P., Hermens, H., & Vollenbroek-Hutten, M. (2014). A telehealth program for self-management of COPD exacerbations and promotion of an active lifestyle: a pilot randomized controlled trial. International journal of chronic obstructive pulmonary disease, 9, 935.

Thakkar, J., Kurup, R., Laba, T. L., Santo, K., Thiagalingam, A., Rodgers, A., ... & Chow, C. K. (2016). Mobile telephone text messaging for medication adherence in chronic disease: a meta-analysis. JAMA internal medicine, 176(3), 340-349.

Theriault L, Hermus G, Goldfarb D, Stonebridge C, Bounajm F. (2012). Cost risk analysis for chronic lung disease in Canada. Conference Board of Canada.

Wang, C. H., Chou, P. C., Joa, W. C., Chen, L. F., Sheng, T. F., Ho, S. C., ... & Kuo, H. P. (2014). Mobile-phone-based home exercise training program decreases systemic inflammation in COPD: a pilot study. BMC pulmonary medicine, 14(1), 142.

Watz, H., Waschki, B., Meyer, T., & Magnussen, H. (2009). Physical activity in patients with COPD. European Respiratory Journal, 33(2), 262-272.

Zhang, J., Song, Y. L., & Bai, C. X. (2013). MIOTIC study: a prospective, multicenter, randomized study to evaluate the long-term efficacy of mobile phone-based Internet of Things in the management of patients with stable COPD. International journal of chronic obstructive pulmonary disease, 8, 433.

# Chapter 3: Perceptions of Health Care Providers Regarding a Mobile Health Intervention to Manage Chronic Obstructive Pulmonary Disease: Qualitative Study

## Preface

A version of this chapter has been published in the Journal of Medical Internet Research (JMIR) - mHealth and uHealth: Alwashmi, M. F., Fitzpatrick, B., Davis, E., Gamble, J. M., Farrell, J., & Hawboldt, J. (2019). Perceptions of Health Care Providers Regarding a Mobile Health Intervention to Manage Chronic Obstructive Pulmonary Disease: Qualitative Study. JMIR mHealth and uHealth, 7(6), e13950. I defined the specific research aim, developed the methods and completed the analysis of case study. I completed the first draft and revised it according to the suggestions of co-authors and reviewers. Dr. John Hawboldt and Dr. Davis suggested the general research topic and provided feedback on the manuscript. Dr. Beverly Fitpatrick helped revise the original manuscript to make the argument clearer. Dr. Jamie Farrell and Dr. John-Michael Gamble reviewed the manuscript and provided revision suggestions. Dr. Jamie Farrell also assisted in recruiting participants.

## Abstract

**Background:** Using a mobile health (mHealth) intervention, consisting of a smartphone and compatible medical device, has the potential to enhance chronic obstructive pulmonary disease (COPD) treatment outcomes while mitigating health care costs.

**Objective:** The aim of this study was to explore the potential facilitators and barriers among health care providers (HCPs) regarding the use of mHealth interventions for COPD management.

**Methods:** This was a qualitative study. Semistructured individual interviews were conducted with HCPs, including nurses, pharmacists, and physicians who work directly with patients with COPD. A flexible prompts guide was used to facilitate discussions. Interview topics included the following: demographics, mHealth usage, perceptions toward challenges of mHealth adoption, factors facilitating mHealth adoption, and preferences regarding features of the mHealth intervention for COPD management. Interviews were conversational in nature, and items were not asked verbatim or in the order presented. The interviews were transcribed verbatim and compared against the digital recordings to ensure the accuracy of the content. After creating a codebook for analysis, two researchers independently coded the interview data using pattern coding. They discussed commonalities and differences in coding until a consensus was reached.

**Results:** A total of 30 nurses, physicians, and pharmacists participated. The main facilitators to mHealth adoption are possible health benefits for patients, ease of use, educating patients and their HCPs, credibility, and reducing cost to the health care system. Alternatively, the barriers to adoption are technical issues, privacy and confidentiality issues, lack of awareness, potential limited uptake from the elderly, potential limited connection between patients and HCPs, and finances.

**Conclusions:** It is important to understand the perceptions of HCPs regarding the adoption of innovative mHealth interventions for COPD management. This study identifies some potential facilitators and barriers that may inform the successful development and implementation of mHealth interventions for COPD management.

## 3.1 Introduction

### 3.1.1 Background

The surge in computing power and mobile connectivity has led to the emergence of mobile health (mHealth) that can transform the mode and quality of clinical research and health care (Steinhubl et al., 2015). mHealth is defined by the National Institutes of Health as the use of mobile and wireless devices to improve health outcomes, health care services, and health research. An mHealth intervention could also include the use of a medical device that is compatible with a smartphone. Evidence suggests that mHealth interventions may benefit patients with many chronic health conditions including chronic obstructive pulmonary disease (COPD) (Alwashmi et al., 2016, Joe & Demiris, 2013, Juen et al., 2015; Zhang et al., 2013).

Although COPD is a preventable and treatable condition, it is estimated to be the third leading cause of death worldwide by 2020 (Murray & Lopez, 1997). According to the Canadian Institute for Health Information, COPD now accounts for the highest rate of hospital admission and readmission among major chronic illnesses in Canada (Canadian Institute for Health Information, 2008). The Conference Board of Canada has stated that the combined direct and indirect costs of COPD will increase from just under CAD $4 billion in 2010 to roughly $9.5 billion by 2030, an increase of 140% (Najafzadeh et al., 2012). Dynamic modeling has shown that any intervention that can reduce the number of exacerbations in a population will have a substantial impact on morbidity and costs associated with COPD (Najafzadeh et al., 2012; Theriault et al., 2012). The authors previously published a systematic review and noted that the current literature on the role of smartphones in reducing COPD exacerbations is limited but does suggest that smartphone interventions may reduce COPD exacerbations (Alwashmi et al., 2016).

### 3.1.2 Importance of Human-Centered Design

The International Organization for Standardization (ISO) 9241-210 standard defines human-centered design (HCD) as “an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques” (ISO, 2010). The ISO uses the term HCD instead of user-centered design to “address impacts on a number of stakeholders, not just those typically considered as users” (ISO, 2010). However, in practice, these terms are often used synonymously.

There is increasing interest from academics and clinicians in harnessing smartphone apps as a means of delivering behavioral interventions for health; however, research on the development and evaluation of such apps is in the relatively early stages (Dennison et al., 2013). Many of the barriers to using mHealth, such as high dropout rates and development costs, can be avoided with better planning and collaboration (Research2Guidance, 2018, Dorsey et al., 2017; WHO, 2017).

Difficulty in using an mHealth intervention may limit the user retention rate. A high dropout rate is one of the most significant barriers to mHealth adoption (Mayberry et al., 2017; Dorsey et al., 2017). The majority of mHealth app publishers (83%) have less than 10,000 users who have used the app at least once a month (Research2Guidance, 2018). These numbers are discouraging as according to a 2018 estimate, the average mHealth app costs $425,000 to develop (Research2Guidance, 2018). By putting a more significant emphasis on usability, iterative improvements can reduce costs and enhance the long-term use and adoption of mHealth interventions (Usability.gov, n.d. a; Ribeiro et al., 2016; Smith et al., 2015).

Testing mHealth interventions with patients has revealed preferences and concerns unique to the tested population (Nelson et al., 2016; Sarkar et al., 2016; Gray et al., 2016). When developing an mHealth intervention, Hopkins et al. (2016) encourage including insights from key users to potentially improve the process and the outcome of the intervention.

Triantafyllidis et al. (2015) used an iterative approach to refine a tablet computer–based home monitoring system for heart failure patients. There was limited uptake of the system owing to usage difficulties and low levels of patient satisfaction. The authors recommended patient-centered approaches for sustainable delivery of remote health monitoring services (Triantafyllidis et al., 2015). Patient-centered care recognizes the complex, subjective, and changing nature of the patient's health status (Upshur et al., 2008); in addition, it links multiple episodes of care offered by diverse providers into continuous, integrated care trajectories unique to particular patients (Boyd & Fortin, 2010; Miller et al., 2015). Developing a COPD mHealth intervention with insights from health care providers (HCPs) working with patients with COPD will potentially improve the process and outcome of the mHealth intervention.

### 3.1.3 Involvement of Health Care Providers

HCD is particularly suited to developing mHealth interventions, which generally involve multiple stakeholders. Bender suggests a collaborative care approach within teams comprising physicians, nurses, pharmacists, and patient advocates to lead to better care and higher patient adherence for complex and comorbid conditions (Bender, 2014). Also, other researchers recommend the involvement of a multidisciplinary team in mHealth interventions to develop tailored messages (Heffernan et al., 2016), address patient medication needs (DiDonato et al., 2015), enhance physical activity in patients with COPD (Vorrink et al., 2016), and support the management of heart failure (Triantafyllidis et al., 2015), diabetes (Jo & Park, 2016), and cancer

(Smith et al., 2015). Chiang et al. (2015) stated that few studies have examined the obstacles faced by HCPs when carrying out telehealth interventions. Similar obstacles in mHealth need to be addressed.

Nursing, medicine, and pharmacy are some of the largest health professions in Canada. Nurses promote COPD management by supportive, preventive, therapeutic, palliative, and rehabilitative means to gain or maintain optimal function (Ministry of Health and Long Term Care, 2018). Physicians assess the condition of COPD and diagnose, treat, and prevent any disease, disorder, or dysfunction whereas pharmacists play a role in the promotion of health, prevention, and treatment of COPD through monitoring and management of medication therapy (Ministry of Health and Long Term Care, 2018). Furthermore, the role of pharmacists has shifted from drug dispensing responsibilities to the provision of direct patient care (Hepler et al., 2002). By obtaining the perspectives of nurses, physicians, and pharmacists, we hope to understand the facilitators and barriers affecting some of the largest health professions in Canada. Furthermore, it will enable us to understand the differences in requirements for an mHealth intervention.

### 3.1.4 Involvement of Health Care Providers Human-Centered Design in Chronic Obstructive Pulmonary Disease

Although mHealth is gaining popularity in recent years, patient and HCP perspectives toward using mHealth for COPD management are relatively unexplored (Korpershoek et al., 2018). One study provided insight into the perceptions of COPD patients and their HCPs toward using mHealth for COPD management. They stated that potential barriers to use mHealth include the following: patients avoiding confrontation with the disease, preference for personal contact with an HCP, difficulties with displaying feelings in an application leading to invalid patient measures and lack of trust in advising characteristics of an mHealth intervention, and lack of enthusiasm for mHealth by HCPs (Korpershoek et al., 2018). They also recommended including a larger sample of HCPs with more mHealth experience in future studies to produce a more diverse range of HCP perspectives (Korpershoek et al., 2018).

To improve the success of mHealth solutions in COPD management, we suggest including HCPs who work with patients with COPD in the development process. Lessons learned will bridge the knowledge gap of barriers and facilitators for mHealth uptake in COPD management. It will also be offered as a guide for research and technology developers working with COPD patients and their HCPs.

## 3.2 Methods

### 3.2.1 Purpose

This study was intended to explore and develop an understanding of potential facilitators and barriers that might influence HCPs using mHealth interventions for COPD management.

### 3.2.2 Study Design

We used a descriptive qualitative research design that was grounded in pragmatism (Merriam & Tisdell, 2015; Patton, 2015). Using a qualitative methodology allowed us to achieve an in-depth, contextualized picture of how a diverse sample of HCPs, in this case nurses, pharmacists, and physicians, think and feel about the possibilities and challenges of using mHealth. This has a pragmatic value as mHealth is an emerging option for delivering health care.

### 3.2.3 Recruitment and Study Setting

HCPs involved in the treatment of patients with COPD were eligible to participate. The primary investigator (PI) contacted the Newfoundland and Labrador Medical Association, the Association of Registered Nurses of Newfoundland and Labrador, and the Pharmacists' Association of Newfoundland and Labrador. These organizations were asked to forward a recruitment email to their mailing lists or post it in their websites. Interested HCPs contacted the

PI via email or telephone, who then scheduled appointments to complete the consent forms and conduct the interviews. Our sample consisted of 30 HCPs: 10 nurses, 10 pharmacists, and 10 physicians. The study took place in St. John's, Canada. We conducted some interviews at Memorial University and others at the participants' offices or homes.

We used purposive typical case sampling to gather information that would reflect typical cases of mHealth use (Patton, 2015; Creswell, 2016). We also used a criterion-based selection (Patton, 2015) so that we could categorize participant characteristics such as age, familiarity with mHealth, health care profession, and years of experience. In addition, as the interviews progressed, some participants were recruited by snowball or chain sampling, where participants suggested other possible HCPs (Patton, 2015; Emerson, 2015). Snowball or chain sampling was used to ask a few information-rich participants for additional contacts to provide confirming or different perspectives, allowing for richer data (Patton, 2015).

Participants were recruited from April 2018 to August 2018. We first contacted nurses, and after interviewing 8 nurses, we reached saturation as we were not gathering new information. However, we continued interviewing until 10 nurses were interviewed. This was to strengthen the validity of inferences (Maxwell, 2013). We used the same sampling strategy for the remaining professions, with similar saturation points and continuing to interview the 10 participants for each profession. Our final sample size was comparable with similar qualitative studies (Korpershoek et al., 2018; Damhus et al., 2018; MacDonald et al., 2018).

### 3.2.4 Ethical Considerations

Ethical approval for this study was obtained from the Newfoundland and Labrador Health Research Ethics Authority (HREB -2017-194). Before agreeing to participate, all subjects were informed about the nature of the research project, possible risks and benefits, and their rights as research subjects. All participants completed a written consent form. They were also given a copy of the consent form.

### 3.2.5 Data Collection

We conducted individual semistructured interviews to gain an understanding of the everyday life-worlds of HCPs in relation to using mHealth (Brinkman & Kvale, 2015). Using semistructured interviews allowed the interviewer to begin with a broad question to direct the focus of the interview and then to provide an opportunity for the HCPs to bring forth their thoughts and feelings about the phenomenon that they thought were important (Brinkman & Kvale, 2015; Rubin & Rubin, 2012). The interview prompts are available in Appendix 1. If participants identified that they have not used mHealth, they were asked questions pertaining to why they had not used mHealth (barriers). However, we did not ask them about facilitators because they did not have the experience to answer these questions. To facilitate discussions, the interviews were conversational in nature and items were not asked verbatim or in the order presented. As the study progressed, emerging issues were explored with subsequent participants to refine the themes. The prompts were informed by findings from the literature and input from the authors who have diverse backgrounds including mHealth, pharmacy, nursing, medicine, respirology, family medicine, education, and qualitative research.

The interviews were recorded to enable transparent and accurate transcription. Interview lengths ranged from 20 to 60 min. Topics included the following: demographics, mHealth usage, perceptions toward challenges of mHealth adoption, factors facilitating mHealth adoption, and preferences regarding features of the mHealth intervention for COPD management. Owing to the large amount of data, preferences regarding features of the mHealth intervention will be published in another article. Data consisted of more than 13 hours of interview time with approximately 300 pages of transcription.

### 3.2.6 Data Analysis

The interviews were transcribed verbatim and compared against the digital recordings to ensure the accuracy of the content. Identifying information (names) was removed to protect anonymity. We used NVivo (version 12; QSR International) to organize the data and examine the words, including frequency counts, as in classical content analysis (Leech & Onwuegbuzie, 2008). All data were analyzed, but we only coded the data that were relevant for answering the research questions, as recommended by Saldana (2016), Wolcott (2009), and Yin (2016). An audit trail was created to keep track of all analytic decisions (Guest et al., 2012).

After using NVivo, we used first cycle coding with the nurses' data that were both structural and holistic (Saldana, 2016), meaning that we used the interview prompts and the literature to guide some of the coding. One researcher analyzed the transcripts and developed a set of themes and subthemes and then obtained input from a second researcher. In the second cycle of coding, the 2 researchers independently coded the nurses' data using pattern coding to develop themes (Saldana, 2016). They then discussed commonalities and differences in their coding and theme development until a consensus was reached. The analysis of the nurses' data was mainly inductive and iterative throughout as we went back and forth among the data, the coding, and the themes (Miles et al., 2014).

After the nursing analysis was finished, we completed the same 2 cycles of analysis for the pharmacist and physician data. These 2 analyses included inductive and deductive analysis. However, the analysis was more deductive in nature as themes had already been developed from the nursing data. The iterative process continued as these analyses were conducted to find commonalities, differences, and new patterns in thinking in relation to the nurses' data. Once these 3 sets of analysis were complete, the 2 researchers discussed common and different trends among the 3 HCP groups to develop final themes that encompassed all the HCPs.

## 3.3 Results

### 3.3.1 Demographics

The sample included HCPs who worked with patients with COPD in various settings, including respirology clinics, cancer clinics, critical care, long-term care, and community health. Some HCPs founded a medical technology company or had a software programming background. About half of the HCPs had experience with an mHealth intervention to manage COPD. Participant demographics are outlined in Table 3.1.

**Table 3.1** Participant demographics.

| **Demographics** | **Sample size** | **Age (years), mean (SD)** | **Years of experience, mean (SD)** |
|---|---|---|---|
| Nurses | 5 | 47.3 (6) | 19.6 (9) |
| mHealth nurses[a] | 5 | 40.6 (10) | 15.8 (10) |
| Physicians | 5 | 37 (9) | 8.4 (8.7) |
| mHealth physicians | 5 | 41.2 (12) | 14.4 (11) |
| Pharmacists | 7 | 35.7 (11) | 11.4 (10) |
| mHealth pharmacists | 3 | 27.5 (4) | 3.6 (2) |

[a]mHealth: Experience in using a mobile health intervention.

The majority of HCPs thought that mHealth can play a role in COPD management; however, some HCPs had opposing views. One nurse who implements an mHealth intervention to manage COPD indicated that "... the majority of our patients are very sad to leave the programme." However, one physician expressed his concern:

*there hasn't been a lot of evidence to prove that this makes a difference in terms of patient outcomes... I think those people are just happy to have another set of eyes watching them, right. I think it probably gives them reassurance.*

Finally, a pharmacist said, "There's obviously going to be some patients who don't want to do it who are technology averse in which case that's totally fine, they can use the traditional methods."

We developed themes under 2 categories: facilitators and barriers that would influence the feasibility and use of mHealth. Table 3.2 summarizes the main facilitators and Table 3.3 summarizes the main barriers. We have also included details and examples to illustrate the HCPs' thoughts and beliefs.

### 3.3.2 Facilitators

**Table 3.2:** Themes with specific examples regarding the facilitators of mHealth adoption.

| Theme | Specific examples for each theme |
|---|---|
| There are possible health benefits for patients | Patients can become more readily educated about their disease; In areas with limited access to health care, mHealth[a] technologies can bridge the gap between patients and health care providers; Patients can become more motivated, empowered, and accountable with managing their health care |
| The software needs to be easy to use | The technology needs to be simple; The language should be basic; The software should be visually appealing |
| Health care providers and patients need to be educated on the use of mHealth | Educational strategies are needed |
| The credibility of mHealth should be evident | Evidence about the effectiveness of mHealth is important; The credibility of the developer is important |

| | |
|---|---|
| mHealth should reduce the cost to the health care system | It results in a decreased use of health care resources; It is affordable owing to the reduced cost of medical devices, and it does not include a large physical infrastructure; Partnering with private entities could facilitate uptake |

[a]mHealth: mobile health.

#### *3.3.2.1 There are Possible Health Benefits for Patients*

Pharmacists, nurses, and physicians agreed that mHealth has the potential to provide health benefits to patients. One nurse, who was experienced with mHealth remarked, “It could make life for them, you know, much easier, and improve their quality of life.” Another nurse felt confident that patients would be “more educated about their diseases and about what things they should be looking for.” A physician commented on his patients who were enrolled in an mHealth intervention program, “... I think those people are just happy to have another set of eyes watching them, right. I think it probably gives them reassurance.”

Some HCPs mentioned that mHealth could increase patient autonomy through simulating empowerment and motivation in patients. The following physician statement represents thoughts from several other HCPs, “it would give patients the power to then be a part of their management plan, which is better when patients are empowered, because they feel in control of their health.” A few pharmacists also mentioned increased motivation as part of this same vein of thought and talked about “access to motivation or making the patient really feel like they were more kind of involved in their own healthcare.” Some nurses indicated that mHealth interventions could provide a sense of accountability:

> *There’s a sense of accountability I believe from the patients. The nurse is watching me this morning, I better do it because she’ll be waiting or he’ll be waiting, definitely.*

Access to health care in rural areas was also thought to be an important facilitator. Many HCPs highlighted the importance of mHealth in reducing travel time and improving access to rural areas (Newfoundland and Labrador, Canada). A nurse observed, “you look at all these small communities in and around the island, those people could certainly benefit from some kind of remote monitoring.” This thought was reinforced by others, as in this physician statement, “I think that is probably the best benefit from Mobile Health in this province is that it can reach some of those rural communities where we can’t go and see patients.” As part of rural health care, it was consistently noted that mHealth would make it easier for HCPs to provide care. For example, a nurse pointed out that mHealth would help with management of time and perhaps allow for more patients to be monitored, as the following comment demonstrates, “what they can achieve in a video appointment is sometimes quicker, and a bit more targeted and efficient, and they can fit them in within their other appointments.”

mHealth should reduce cancelled appointments and hospital visits as patients would not have to leave their homes, in urban as well as in rural areas. One physician expressed this concern about hospital visits, coupled with the advantage of mHealth:

> *you can just send that from home. Not even have to go into a facility. And sometimes that’s really onerous for people, especially people who are suffering from COPD, so they’re going to have shortness of breath and exertion and find it even harder to get from the parking lot into the hospital, so the more you can do to make their lives easier, it’s great.*

#### *3.3.2.2 The Software Needs to Be Easy to Use*

Usability was highlighted by the majority of HCPs as an important factor in increasing the uptake of mHealth. One nurse with experience in conducting mHealth interventions cautioned that patients may stop using the intervention owing to usability issues:

> *they found it hard, I'd say largely related to the technology, not being able to handle it or finding it too much work. Too tiring, too much trouble, not for them, that kind of thing.*

Thus, most HCPs recommended the software to be easy to use. As another nurse pointed out:

> *people are overwhelmed when they are diagnosed with something that is new and complicated, and affects something as important as your breathing. So, this has got to be something that is easy for them to access and, I think, easy for them to see benefits from.*

Some pharmacists recommended using simple language to enhance usability, as in "it needs to be kept useful, but also simple enough for them to be able to navigate and use." One nurse reinforced this notion and thought the language should be "set at a grade six reading level, so there's no issues with comprehension of what they're being asked or told." It was also thought that the software should be visually appealing, with color and perhaps daily progress or weekly tracking graphs. Font size was also raised as an issue. One nurse quipped, "people my age and above can't see. A lot of it is very tiny, so the need for reading glasses." This was apt as COPD generally develops in later stages of life.

In addition, one nurse with experience in mHealth interventions said HCPs may not use the intervention if it was difficult to use, "where the provider is getting all this information, doesn't feel that comfortable sorting through it, or using it to make clinical decisions, and then it just is going to no use it." So, users and providers need software that is easy to use as well as comprehensive. To streamline the physician workflow, one physician suggested that data collected by the mHealth intervention should be accessed via the electronic medical record: "I have an electronic medical record so it would be nice if it was actually in electronic format."

#### *3.3.2.3 Health Care Providers and Patients Need to Be Educated on the Use of Mobile Health*

It was recognized that mHealth is a different type of learning for many HCPs as it includes learning about technology instead of diseases. However, as one nurse rationalized, "we need to make sure we are staying up and current and on top of this." Many strategies were suggested for educating HCPs, such as integrating information about digital health and mHealth in school curricula; self-learning; Web-based learning; learning from coworkers, students, and sales representatives; attending educational sessions; and hiring coordinators for support.

The necessity to educate patients was also acknowledged. As one pharmacist suggested, "I guess most patients with COPD are older and would probably benefit from someone walking through the app with them and showing them how to use it." Hands-on learning, supplementary print materials, and a video tutorial were suggested as ways to teach patients how to use the software. Others mentioned the convenience of having family support as an enabler.

In terms of who should teach patients, it was thought by some that HCPs should share the responsibility. As advocated by one pharmacist:

> *I guess anyone, if you're seeing a patient or person who is in need of that service could introduce it. I don't think one person should have to take all the responsibility, or one profession.*

However, this was not an agreed upon idea. Some thought there should be designated people to teach the necessary skills, but there were differing opinions about which group of HCPs should lead the patient education. It was also recommended by some that technical support staff be available as a resource for patients to call when they needed technical help.

#### *3.3.2.4 The Credibility of Mobile Health Should Be Evident*

HCPs thought that the credibility of mHealth needs to be made evident to HCPs and patients. This would help raise awareness to facilitate uptake by HCPs. A physician worded it like this, “if I perceived that this is something that would help someone exercise a little bit more, control their weight, watch their diet, then I would recommend that.” A nurse was even more specific in terms of evidence:

> *it would be really important to have some solid, really good evidence to show that, in actual fact, we receive excellent outcomes in terms of quality of life indicators, activity levels, medication usage at a specific time point, be it within one or two years, to decide that this type of monitoring, and this type of connection with your provider is making a difference to your outcomes. I think that type of evidence is what’s going to change my mind as a practitioner about whether it’s worth using it or not.*

This sentiment was reiterated by a pharmacist who thought that “knowing if there’s evidence to actually support its use” was essential.

In addition, the credibility of the developer was mentioned, as in this statement from a pharmacist, “it’s also about the credibility of who’s putting the app together.” Added to this, recommendations from credible HCPs were also thought to be important. One physician commented:

> *I mean, the power of one's network. If I view something and I think that it’s good, then me giving it a vote of confidence that would then get shared, and people would know that I am independently choosing to recommend something.*

#### *3.3.2.5 Mobile Health Should Reduce the Cost to the Health Care System*

It was thought that mHealth has the ability to provide the "clinical assessment and healthcare that was required in a more cost-effective manner", as recommended by one of the nurses. It should decrease emergency visits and hospital admissions, as explained by a nurse who thought it would "hopefully catch things in the earlier stage before these patients who were mostly elderly got in enough trouble that they would end up in the emergency department."

Advancements in mHealth can result in a decrease in expenses, as a third nurse explained, "I can send a patient a whole set of devices including a blood pressure cuff, O2 sat machine and a weigh scale for less than 300 dollars."

Large physical infrastructure would not be required, and it was suggested that some of this could be outsourced to private entities that are already doing this type of work, thereby reducing expenses to taxpayers.

### 3.3.3 Barriers

**Table 3.3:** Themes with specific examples regarding the barriers of mHealth adoption.

| **Theme** | **Specific examples for each theme** |
|---|---|
| There are technical issues with mHealth[a] | It may include equipment malfunction, password issues, and interoperability; It requires internet access; Many clinics are paper based |
| There may be privacy and confidentiality concerns | People, other than the patients, might gain access to private information |
| Lack of awareness is a challenge | Many HCPs[b] and patients are not aware of the current advancements in mHealth |
| There may be limited uptake from the elderly | Some HCPs thought older age may be a barrier to technology adoption; Some believed the upcoming generation will be more familiar with technology |
| mHealth may limit the personal connection between HCPs and patients | Some thought personal connections are necessary; Others thought the advantages of mHealth outweigh personal connections; Others thought a hybrid approach might be optimal |
| There are possible financial barriers; There were a few challenges mentioned by a minority of HCPs | This includes the high cost of the mHealth intervention, time consumption, and lack of billing codes for HCPs; These included false sense of security, anxiety, lack of motivation, and loss to follow up. |

[a]mHealth: mobile health.
[b]HCP: health care provider.

#### *3.3.3.1 There Are Technical Issues With Mobile Health*

Many HCPs expressed that technical issues can be barriers for mHealth adoption. Specifically, equipment malfunction, password issues, and interoperability were mentioned frequently. For example, a nurse reported, "there's been issues with the technology not communicating because we have setups in four different ways." In addition, some technical specifications are required, such as the smartphone being Bluetooth compatible, along with cellular and Wi-Fi connections being available. One nurse elaborated, "there are patients within little pockets of ... that don't have cellular service or Internet connection, so unfortunately those patients will not be able to be referred to the program." Another limiting condition to sharing mHealth data via electronic medical records was mentioned by physicians, in that many clinics are still paper based or not up to date in technology use.

#### *3.3.3.2 There May Be Privacy and Confidentiality Concerns*

A few HCPs thought privacy and confidentiality could be a barrier to mHealth adoption. A pharmacist, echoing other HCPs, questioned, "how are patients confident that the information that's in that app is only going to stay with them and that other people are not going to see that data?" The concern of family members viewing private information was raised, "patients, you know, if they're competent they don't want their family members to see their information and that could be an issue." Also, the issue of stolen or lost phones that contained private information was raised.

However, other HCPs thought these issues could be mitigated with security, as expressed by a pharmacist, "if it is secure and the patient gets to decide who accesses it, I don't see it being an issue with confidentiality." And, some HCPs, as noted by a nurse, were ambivalent regarding privacy and confidentiality, “I wouldn’t imagine that there are any more privacy concerns than there are with anything else within health care.”

#### *3.3.3.3 Lack of Awareness Is a Challenge*

mHealth experience expressed this concern “I think if that had been a part of my training more and I’d seen it more then it could definitely become part of my own training.” Employers’ lack of knowledge was also mentioned. For example, a nurse shared:

> *Our employer doesn’t want to see us having them out, people will have the impression we are using it for personal use. That is one big factor. Our employer tells us, keep your phones hidden, don’t have them out.*

#### *3.3.3.4 There May Be Limited Uptake From the Elderly*

HCPs had conflicting opinions regarding age and mHealth adoption. All physicians and some nurses and pharmacists agreed that the elderly may face issues in adopting these technologies, as indicated by this pharmacist, “a lot of the patients with COPD being older and maybe not as app-savvy as the group that you’re aiming towards.” This thought was reinforced by one physician’s words, with a caveat of doubt, “I suppose I would assume that the elderly and the more frail would not be tech-savvy, though, I know smartphone use is increasing with the ageing population.” This caveat was supported by some of the nurses with an mHealth experience, as expressed by one experienced nurse:

> *I had patients who are older than 90 who never owned a computer in their life and managed to do their sessions on their iPads and send it to me with no trouble. So, I think it depends on maybe education level and understanding, and maybe how things are explained to them.*

A couple of pharmacists experienced in mHealth even stated that some elderly people have embraced technology:

> *I've had a lot of kind of older generation patients that once we've kind of sat down they've said oh I've been tracking this or I have this app, and I was kind of shocked. So until you kind of try it out and recommend it to people you never know what they're open to using or what they're already using.*

It was also thought by some that the upcoming generation will be more familiar with technology, as a nurse surmised, "We have to be sensitive to the fact that technology is present in my world, it's present in yours, but it wasn't in my grandparents." Some physicians also thought that future generations will value and use mHealth more than the current generation, "I think the younger generation will, you know, take this in very easily and very much accept it, so I think going forward there's only going to be more of it, not less."

It was also posited that some older HCPs may face issues when adopting mHealth, as put forward by one pharmacist: "I'm sure there'd be some potentially older pharmacists who are less familiar with smartphones and apps that might have more trouble, and may benefit from a tutorial type thing." This was reiterated by a physician:

> *I think that probably technology maybe gets pushed to the side. I think that a lot of the physicians too might be, not scared but reluctant to use technology and to learn a new skill, especially if they've been in practice for thirty years or something.*

#### *3.3.3.5 Mobile Health May Limit the Personal Connection Between Health Care Providers and Patients*

As with age, HCPs had conflicting opinions about mHealth and building personal connections between patients and HCPs. A nurse who worried that mHealth might limit the personal connections said:

> *I like to have a bit of actual contact and eye contact, and hear the tone of someone's voice, and a gentle touch sometimes can be so reassuring, you know. I think it's going to be lost with this type of technology.*

However, this same nurse added that even minimal contact could mitigate that barrier, as in "I think there needs to be some sort of human contact, even if it is just the face of the person who receives that information."

Some physicians also agreed that mHealth lacks this type of contact, as in "I don't think you're ever going to really replace that human element." However, although it was emphasized that interacting with patients face to face is better than online, some HCPs struggled with the advantages of human contact versus access. One nurse who was a champion of human contact, recognized that mHealth is " increasing access and to me, that would be a better benefit than the actual face to face, to be able to reach more people more often." Then there were nurses experienced in mHealth who thought it could enhance the personal connection, as in "I think the bond is actually a bit more in this program than it was when I was a bedside nurse in some ways, because you're getting more personal with the patient about other aspects of their healthcare as well." One nurse reported that she had done surveys about patient satisfaction, provider satisfaction, and support staff satisfaction and "the surveys, they do come back that it's similar if not better than a face-to-face."

The majority of physicians, and many pharmacists, thought mHealth has the potential to improve personal connections. This pharmacist's statement represents a commonly expressed example of how this could happen:

> *I think it would strengthen that relationship because you could ask them about their apps and go through it with them when they come other than just seeing if they're late using their prescriptions or late picking them up or anything.*

Some HCPs suggested a hybrid model so that mHealth could supplement the personal connection, as in this physician's comment, "Do I think that it could totally replace it, absolutely not... but can I see it being hand-in-and, absolutely." This sentiment was supported by another physician, "I would like to see them for the initial consultation, but I think for follow-up reports, you know, we could save them great distances from travelling." and supported by a nurse, as in " I think having regular face-to-face contacts intermittently is still a very important part of healthcare, and it's something that I think will never be completely removed."

#### *3.3.3.6 There Are Possible Financial Barriers*

HCPs had conflicting opinions about financial implications. A few HCPs said some patients with COPD may not be able to afford mHealth and do not have access to smartphones. One physician expressed it this way, "generally more patients with COPD are falling in the lower socio-economic grouping that wouldn't necessarily be able to afford this." A nurse with experience conducting mHealth programs endorsed this concern by adding that only about 10% of participants may remain in the mHealth intervention if the insurance company stopped paying for the service.

In addition to individual patient costs, there is the initial cost of establishing the infrastructure, including costs related to storing data in the cloud. In addition, costs related to the maintenance and replacement of outdated technology were discussed, as reinforced by one nurse, “there’s a number of equipment across the province that are nine years old, and if they die then there’s no replacement.” In addition, some mHealth programs are limited to a certain period. Participants may get medical devices (e.g., blood pressure monitors and pulse oximeters) that have to be returned for cleaning to be used by other participants. One experienced nurse complained that getting medical devices back from patients can be problematic, as in:

> *I have actually been at the plants, the facilities where we get them back and clean them. And cockroaches in the boxes that were coming back and just swilled with feces and blood and so on. It is just... They have been horrendous.*

Most physicians thought lack of time was a major challenge. They mentioned time to learn about mHealth themselves, time to teach patients, and time to review the results of the mHealth intervention. One physician gave this example, “when you get a 12 page report on one patient and you’re seeing 40 patients a day and you know time constraints with the amount of work that you do outside in terms of paperwork is already a burden.”

Pharmacists had contradictory views about time. A few pharmacists thought lack of time could be a barrier, as in:

> *Most pharmacists are quite busy as it is... I see the workload potentially going up because now if patients are using this they can’t forget to write things down or lose what they documented. It’s all there for them, so now they bring the information in.*

Alternatively, other pharmacists thought that mHealth could save time by collecting information required in advance “with the expanded pharmacists role we’re building more time to spend with our patients and in that sense we will have that time to teach them and to monitor some of these new technologies that are coming up.”

Lack of reimbursement and billing codes were also mentioned as barriers. One experienced pharmacist explained:

> *there's not a whole lot of reimbursement for services like this and like that's the biggest barrier with most things within the pharmacy profession...doing like daily monitoring on patients like is time-consuming and we definitely want to do it but unfortunately like it does take time and resources and those resources aren't always available.*

In addition, it was emphasized that the lack of billing codes for mHealth is another financial barrier, as a physician insisted:

> *I mean we're all so busy that nobody wants to do anything for free because why would I do that for free if I get paid for it. So that's a barrier that has to be overcome is that how do you change some of the way physicians are paid. There's no incentivizing the optimized care as an example. If I do a poor quality of care for my COPD patient or if I do an excellent quality of care, it's the same payment. So there's a problem with the system in that sense and physicians in general would be resistant to sort of evaluate how well they're doing with their patients.*

#### *3.3.3.7 There Were a Few Challenges Mentioned by a Minority of Health Care Providers*

There were additional challenges that were mentioned by small numbers of HCPs. For example, one physician thought patients may gain "a false sense of security" about their health status, owing to technology. Another physician voiced concern that "some sub-groups of patients with anxiety might have impaired quality of life because then they become obsessed with that rather than actually just saying okay that's what they're saying, I'm okay." A pharmacist questioned validity:

*the validity of the data would be something that some people might question. I guess a lot of that would depend on how straightforward the devices are to use or how much training might be required to make sure that they are using it correctly.*

Motivation to continue using the intervention was also a concern. A pharmacist wondered, "I think getting patients to use it and use it often enough might be difficult, depending on the patient." A few pharmacists and physicians noted that many patients with COPD are not motivated to manage their disease. One pharmacist commented:

> *The biggest challenge I find with COPD patients, now that's the population that I deal with, is that they are smokers and continue to smoke, the majority of them. Their education level is probably a little bit on the lower side and that's related to the whole smoking, right, that kind of thing, the socio-economic status of the patient. So they're not necessarily invested in improving their health with a lot of effort, right. They'll take an inhaler, take a pill to help them get better, but really changing their lifestyle and their smoking is not high on their list.*

One nurse highlighted that about 30% of patients dropped out after using an mHealth intervention.

## 3.4 Discussion

### 3.4.1 Principal Findings

This qualitative study found that HCPs, in general, had a positive attitude toward mHealth adoption for COPD management, but several facilitators and barriers were identified. More barriers were identified than facilitators, indicating a need to address these barriers to optimize successful implementation of mHealth interventions.

To facilitate mHealth uptake, our thoughts, based on the data, are that both HCPs and patients need to understand the potential benefits of the mHealth intervention. The interventions must be easy to use for both patients and HCPs. This could reduce the time and resources required to teach patients and providers about the mHealth intervention. One physician stated that the use of mHealth interventions could provide a false sense of security, thereby keeping the user from seeking medical advice in a timely manner. This concern along with the lack of awareness concerned HCPs, an important finding is the need for HCPs to teach patients about mHealth interventions. Some HCPs thought there should be a designated person to teach patients. It is preferable that these professionals have a background in chronic disease management and technical support.

There were a few barriers identified by the HCPs. Most of these barriers have the potential to be resolved, as suggested by many of the HCPs. Technical issues continue to be a challenge for mHealth adoption, especially for rural areas and developing countries that have poor connection network.

### 3.4.2 Comparison With Previous Work

Although the numbers of HCPs using mHealth interventions are growing, studies focusing solely on the frontline staff perspective on mHealth are limited (Damhus et al., 2018; Brunton et al., 2015). Some of the findings presented in this study confirm findings that have been reported previously in the context of mHealth for COPD management. As Damhus et al (2018) noted, HCPs reported technical issues as a major challenge for mHealth adoption. Our findings are in agreement with Vorrink et al. (2017), who stress the importance of training patients and HCPs on the proper use of mHealth. In this study, as well as other studies, we have noted that mHealth will not replace face-to-face interactions (Korpershoek et al., 2018; Damhus et al., 2018; Vorrink et al., 2017). In agreement with Damhus et al. (2018) and Korpershoek et al. (2018), we suggest that the expected benefits of using mHealth contribute to the success of mHealth uptake, although our study provides additional insight with regard to these perceptions.

### 3.4.3 Strengths and Limitations

There are several strengths of this study. First, this research is based on a diverse sample of participants. It includes various perspectives by presenting the views of nurses, pharmacist, and physicians, including a respirologist. This human-centered approach ensures that needs and challenges of different people involved in the management of COPD can be considered before developing an mHealth intervention. Second, some HCPs had experience in using an mHealth intervention to manage COPD which further increases the richness of the data. Third, all of the interviews were conducted in a similar manner to ensure consistency during the data collection and analysis. Finally, mHealth is particularly important in geographic locations with relatively large proportions of rural residents such as Newfoundland and Labrador. mHealth may enhance care provider access throughout sparsely populated rural areas. Newfoundland and Labrador has a substantial remote and rural population, therefore our results may be more applicable to rural areas.

There were also several limitations. First, not all the HCPs had experience with using mHealth. Thus, the perceptions of these participants were not based on actual interventions with patients. Second, we used only one data collection method, thus not triangulating data collection. Conducting focus groups with some of the participants following the individual interviews could have yielded richer information as participants would have been given the opportunity to compare their thoughts and confirm or expand upon each other’s ideas. This would be a recommendation for a future study.

### 3.4.4 Implications for Practice

The findings of this study provide insights into the barriers and facilitators for using mHealth as a part of COPD management. This information may help a variety of stakeholders who are planning to use mHealth interventions for COPD management. Lessons learned include the importance of raising an awareness among patients with COPD and HCPs regarding the potential of mHealth interventions in COPD management. Professional associations and universities could play a significant role in raising an awareness of, and even introducing, mHealth in undergraduate health professional curricula. It also may be beneficial to designate an HCP, with a background in chronic disease management and technical support, to teach patients about mHealth.

The findings emphasize the importance of developing a user-friendly mHealth intervention. This could reduce the time and resources required to teach patients and providers about the mHealth intervention. In addition, the lack of an internet connection limits access to mHealth interventions, so this should be taken into consideration when measuring access to health resources in rural communities.

In terms of credibility, health organizations such as the Food and Drug Administration, Health Canada, or the Canadian Association for Drugs and Technologies should take an active role in regulating mHealth interventions. These organizations can develop their own app stores, similar to the Veteran Affairs app store, to showcase credible mHealth interventions. In addition, when developing mHealth interventions, it is important to follow international guidelines for the exchange, integration, sharing, and retrieval of electronic health information (Health Level 7, 2018). This could help in addressing interoperability issues. Nevertheless, these regulations should be implemented in a manner that supports mHealth uptake.

### 3.4.5 Recommendations for Future Research

Future studies would benefit from conducting focus groups with some of the participants following the individual interviews. Focus groups could yield richer information as participants would be given the opportunity to compare their thoughts and confirm or expand upon each other's ideas. Furthermore, including the perspectives of allied HCPs, such as physiotherapists, social workers, and occupational therapists, would be beneficial to understand the perspectives of administrators (e.g., information technology managers) who may be able to identify some of the challenges with using mHealth for COPD management. The authors have conducted a similar study with a focus on the perspectives of individuals with COPD. In addition, a future article will focus solely on the features of the ideal mHealth intervention for COPD management. After developing a user-centered mHealth intervention, the authors recommend using a mixed methods framework for usability testing (Alwashmi et al., 2019).

## 3.5 Conclusions

It is important to understand the perceptions of HCPs regarding the adoption of innovative mHealth interventions for COPD management. This study identifies the facilitators and barriers that may aid in the successful development and implementation of mHealth interventions for COPD management. Lessons from this study may also be applied to other chronic diseases. Additional research is needed to investigate the conflicting opinions regarding mHealth adoption by the elderly, the personal communication between HCPs and patients, and the cost-effectiveness of mHealth interventions in COPD management.

## 3.6 References

Alwashmi, M., Hawboldt, J., Davis, E., Marra, C., Gamble, J. M., & Ashour, W. A. (2016). The effect of smartphone interventions on patients with chronic obstructive pulmonary disease exacerbations: a systematic review and meta-analysis. JMIR mHealth and uHealth, 4(3), e105.

Alwashmi, M. F., Hawboldt, J., Davis, E., & Fetters, M. D. (2019). The iterative convergent design for mobile health usability testing: mixed-methods approach. JMIR mHealth and uHealth, 7(4), e11656.

Bender, B. G. (2014). Nonadherence in chronic obstructive pulmonary disease patients: what do we know and what should we do next?. Current opinion in pulmonary medicine, 20(2), 132-137.

Boyd, C. M., & Fortin, M. (2010). Future of multimorbidity research: how should understanding of multimorbidity inform health system design?. Public Health Reviews, 32(2), 451.

Brinkmann, S., & Kvale, S. (2015). InterViews: Learning the craft of qualitative research interviewing. Sage Publications.

Brunton, L., Bower, P., & Sanders, C. (2015). The contradictions of telehealth user experience in chronic obstructive pulmonary disease (COPD): a qualitative meta-synthesis. PLoS One, 10(10), e0139561.

Canadian Institute for Health Information, (2008). Health Indicators. Retrieved from URL: https://secure.cihi.ca/free_products/HealthIndicators2008_ENGweb.pdf

Chiang, K. F., Wang, H. H., Chien, I. K., Liou, J. K., Hung, C. L., Huang, C. M., & Yang, F. Y. (2015). Healthcare providers' perceptions of barriers in implementing of home telecare in Taiwan: a qualitative study. International journal of medical informatics, 84(4), 277-287.

Creswell, J. W. (2016). 30 essential skills for the qualitative researcher. Sage Publications.

Damhus, C. S., Emme, C., & Hansen, H. (2018). Barriers and enablers of COPD telerehabilitation–a frontline staff perspective. International journal of chronic obstructive pulmonary disease, 13, 2473.

Dennison, L., Morrison, L., Conway, G., & Yardley, L. (2013). Opportunities and challenges for smartphone applications in supporting health behavior change: qualitative study. Journal of medical Internet research, 15(4), e86.

DiDonato, K. L., Liu, Y., Lindsey, C. C., Hartwig, D. M., & Stoner, S. C. (2015). Community pharmacy patient perceptions of a pharmacy-initiated mobile technology app to improve adherence. International Journal of Pharmacy Practice, 23(5), 309-319.

Dorsey, E. R., McConnell, M. V., Shaw, S. Y., Trister, A. D., & Friend, S. H. (2017). The use of smartphones for health research. Academic Medicine, 92(2), 157-160.

Emerson, R. W. (2015). Convenience sampling, random sampling, and snowball sampling: How does sampling affect the validity of research?. Journal of Visual Impairment & Blindness, 109(2), 164-168.

Gray, C. S., Khan, A. I., Kuluski, K., McKillop, I., Sharpe, S., Bierman, A. S., ... & Cott, C. (2016). Improving patient experience and primary care quality for patients with complex chronic disease using the electronic patient-reported outcomes tool: adopting qualitative methods into a user-centered design approach. JMIR research protocols, 5(1), e28.

Guest, G., MacQueen, K. M., & Namey, E. E. (2012). Applied thematic analysis. Sage Publications.

Health Level 7, (2018). Mobile health. Retrieved from URL: http://www.hl7.org/Special/committees/mobile/index.cfm

Heffernan, K. J., Chang, S., Maclean, S. T., Callegari, E. T., Garland, S. M., Reavley, N. J., ... & Wark, J. D. (2016). Guidelines and recommendations for developing interactive eHealth apps for complex messaging in health promotion. JMIR mHealth and uHealth, 4(1), e14.

Hepler, C. D., Strand, L. M., Tromp, D., & Sakolchai, S. (2002). Critically examining pharmaceutical care. Journal of the American Pharmaceutical Association (Washington, DC: 1996), 42(5 Suppl 1), S18-9.

Hopkins, I. G., Dunn, K., Bourgeois, F., Rogers, J., & Chiang, V. W. (2016, June). From development to implementation—A smartphone and email-based discharge follow-up program for pediatric patients after hospital discharge. In Healthcare(Vol. 4, No. 2, pp. 109-115). Elsevier.

International Organization for Standardization. (2010). Ergonomics of human-system interaction: Part 210: Human-centred design for interactive systems. ISO.

Jo, S., & Park, H. (2016). Development and evaluation of a smartphone application for managing gestational diabetes mellitus. Healthcare informatics research, 22(1), 11-21.

Joe, J., & Demiris, G. (2013). Older adults and mobile phones for health: a review. Journal of biomedical informatics, 46(5), 947-954.

Juen, J., Cheng, Q., & Schatz, B. (2015). A natural walking monitor for pulmonary patients using mobile phones. IEEE Journal of biomedical and health informatics, 19(4), 1399-1405.

Korpershoek, Y. J., Vervoort, S. C., Trappenburg, J. C., & Schuurmans, M. J. (2018). Perceptions of patients with chronic obstructive pulmonary disease and their health care providers towards using mHealth for self-management of exacerbations: a qualitative study. BMC health services research, 18(1), 757.

Leech, N. L., & Onwuegbuzie, A. J. (2008). Qualitative data analysis: A compendium of techniques and a framework for selection for school psychology research and beyond. School Psychology Quarterly, 23(4), 587.

Macdonald, G. G., Townsend, A. F., Adam, P., Li, L. C., Kerr, S., McDonald, M., & Backman, C. L. (2018). eHealth technologies, multimorbidity, and the office visit: qualitative interview study on the perspectives of physicians and nurses. Journal of medical Internet research, 20(1), e31.

Maxwell, J. A. (2013). Applied social research methods series: Vol. 41. Qualitative research design: An interactive approach, 3.

Merriam, S. B., & Tisdell, E. J. (2015). Qualitative research: A guide to design and implementation. John Wiley & Sons.

Miles, M. B., Huberman, A. M., & Saldana, J. (2014). Qualitative Data Analysis: A Methods Sourcebook. 3rd Edition.

Miller, D., Gray, C. S., Kuluski, K., & Cott, C. (2015). Patient-centered care and patient-reported measures: let's look before we leap. The Patient-Patient-Centered Outcomes Research, 8(4), 293-299.

Ministry of Health and Long-Term Care, (2018). Regulated health professions - health workforce planning branch - health care professionals. Retrieved from URL: http://www.health.gov.on.ca/en/pro/programs/hhrsd/about/regulated_professions.aspx

Murray, C. J., & Lopez, A. D. (1997). Alternative projections of mortality and disability by cause 1990–2020: Global Burden of Disease Study. The Lancet, 349(9064), 1498-1504.

Najafzadeh, M., Marra, C. A., Lynd, L. D., Sadatsafavi, M., FitzGerald, J. M., McManus, B., & Sin, D. (2012). Future impact of various interventions on the burden of COPD in Canada: a dynamic population model. PloS one, 7(10), e46746.

Nelson, L. A., Mayberry, L. S., Wallston, K., Kripalani, S., Bergner, E. M., & Osborn, C. Y. (2016). Development and usability of REACH: a tailored theory-based text messaging intervention for disadvantaged adults with type 2 diabetes. JMIR human factors, 3(2), e23.

Patton, M. Q. (2015). Purposeful sampling and case selections: Overview of strategies and options. Qualitative research & evaluation methods: Integrating theory and practice, 265.

Research2guidance. (2018). mHealth economics - how mHealth app publishers are monetizing their apps. Retrieved from URL: https://research2guidance.com/product/mHealth-economics-how-mHealth-app-publishers-are-monetizing-their-apps/

Rubin, H. J., & Rubin, I. S. (2012). Qualitative interviewing: The art of hearing data. Sage.

Saldaña, J. (2016). The coding manual for qualitative researchers. Sage.

Sarkar, U., Gourley, G. I., Lyles, C. R., Tieu, L., Clarity, C., Newmark, L., ... & Bates, D. W. (2016). Usability of commercially available mobile applications for diverse patients. Journal of general internal medicine, 31(12), 1417-1426.

Smith, S. A., Claridy, M. D., Whitehead, M. S., Sheats, J. Q., Yoo, W., Alema-Mensah, E. A., ... & Coughlin, S. S. (2015). Lifestyle modification experiences of African American breast cancer survivors: a needs assessment. JMIR cancer, 1(2), e9.

Steinhubl, S. R., Muse, E. D., & Topol, E. J. (2015). The emerging field of mobile health. Science translational medicine, 7(283), 283rv3-283rv3.

Theriault L, Hermus G, Goldfarb D, Stonebridge C, Bounajm F. (2012). Cost risk analysis for chronic lung disease in Canada. Conference Board of Canada.

Triantafyllidis, A., Velardo, C., Chantler, T., Shah, S. A., Paton, C., Khorshidi, R., ... & SUPPORT-HF Investigators. (2015). A personalised mobile-based home monitoring system for heart failure: the SUPPORT-HF Study. International journal of medical informatics, 84(10), 743-753.

Upshur, R. E., & Tracy, S. (2008). Chronicity and complexity: is what's good for the diseases always good for the patients?. Canadian Family Physician, 54(12), 1655-1658.

Vorrink, S., Huisman, C., Kort, H., Troosters, T., & Lammers, J. W. (2017). Perceptions of patients with chronic obstructive pulmonary disease and their physiotherapists regarding the use of an eHealth intervention. JMIR human factors, 4(3), e20.

Vorrink, S. N., Kort, H. S., Troosters, T., & Lammers, J. W. J. (2016). A mobile phone app to stimulate daily physical activity in patients with chronic obstructive pulmonary disease: development, feasibility, and pilot studies. JMIR mHealth and uHealth, 4(1), e11.

Wolcott, H. F. (2009). Writing up qualitative research. Sage Publications.

World Health Organization. (2017). A handbook on how to implement mBreatheFreely, mHealth for COPD and asthma.

Yin, R. K. (2016). Qualitative research from start to finish (Second). New York: The.

Zhang, J., Song, Y. L., & Bai, C. X. (2013). MIOTIC study: a prospective, multicenter, randomized study to evaluate the long-term efficacy of mobile phone-based Internet of Things in the management of patients with stable COPD. International journal of chronic obstructive pulmonary disease, 8, 433.

# Chapter 4: Perceptions of Patients With Chronic Obstructive Pulmonary Disease regarding a Mobile Health intervention to manage COPD: a Mixed Methods Study

## Preface

A version of this chapter will be submitted to a suitable journal. I defined the specific research aim, developed the methods, and completed the analysis of the case study. I completed the first draft and revised it according to the suggestions of co-authors and reviewers. Dr. John Hawboldt and Dr. Davis suggested the general research topic and provided feedback on the manuscript. Dr. Beverly Fitzpatrick helped revise the original manuscript to make the argument clearer. Dr. Jamie Farrell also assisted in recruiting participants. Dr. John-Michael Gamble and Dr. Hai Nguyen provided suggestions on how to analyze the quantitative data. The co-authors reviewed the manuscript and provided revision suggestions.


## Abstract

**Background:** Using a mobile health (mHealth) intervention consisting of a smartphone and compatible medical device has the potential to enhance chronic obstructive pulmonary disease (COPD) treatment outcomes while mitigating health care costs.

**Objective:** This study was intended to describe the demographics, use, and access to smartphones of patients with COPD. It also aims to explore and develop an understanding of potential facilitators and barriers that might influence COPD patients using mHealth interventions for COPD management.

**Methods:** This was an explanatory sequential mixed methods study. Patients who attended three respirology clinics completed a questionnaire about technology access and use. Semi-structured individual interviews were conducted with patients. Interview topics included the following:

demographics, mHealth usage, perceptions toward challenges of mHealth adoption, factors facilitating mHealth adoption, and preferences regarding features of the mHealth intervention for COPD management.

**Results:** A total of 100 adults completed the survey but 23 patients were excluded because they were not diagnosed with COPD. Of those, 10 patients with COPD participated in the interview. The quantitative component revealed that many COPD patients owned a mobile phone, but only about a quarter of the participants, 18/77 (23.4%), owned a smartphone. The likelihood of owning a smartphone was not associated with age, sex, marital status, or geographical location, but patients with high educational status are more likely to own a smartphone. The qualitative component found that COPD patients, in general, had a positive attitude toward mHealth adoption for COPD management, but several facilitators and barriers were identified. The main facilitators to mHealth adoption are possible health benefits for patients, ease of use, educating patients, and credibility. Alternatively, the barriers to adoption are technical issues, lack of awareness, potential limited uptake from the elderly, privacy and confidentiality issues, finances, and lack of interest in mHealth".

**Conclusions:** It is important to understand the perceptions of patients with COPD regarding the adoption of innovative mHealth interventions for COPD management. This study identifies some potential facilitators and barriers that may inform the successful development and implementation of mHealth interventions for COPD management.

## 4.1 Introduction

Advancements in mobile phones and communication technologies have led to the inception of mobile health (mHealth), which can transform clinical research and healthcare (Steinhubl, Muse, & Topol, 2015). mHealth is defined by the National Institutes of Health as the "use of mobile and wireless devices to improve health outcomes, healthcare services, and health research". An mHealth intervention could also include the use of a medical device that is compatible with a smartphone. Previous research suggests that mHealth interventions may benefit patients with many chronic health conditions, including Chronic Obstructive Pulmonary Disease (COPD) (Alwashmi et al., 2016; Joe & Demiris, 2013; Juen, Qian Cheng, & Schatz, 2015; Zhang, Song, & Bai, 2013).

Alwashmi et al. (2016) noted that the current literature on the role of smartphones in reducing COPD exacerbations is limited, but they suggest that mHealth interventions may reduce COPD exacerbations. To potentially enhance the adoption and outcome of the mHealth intervention, key users should be involved in the development of these interventions.

### 4.1.1 Importance of Human-Centered Design

The International Organization for Standardization (ISO) 9241-210 standard defines human-centered design (HCD) as "an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" (ISO, 2010). The ISO uses the term HCD instead of user-centered design (UCD) to "address impacts on a number of stakeholders, not just those typically considered as users" (ISO, 2010). However, in practice, these terms are often used synonymously.

Many researchers use mHealth to assist in the management of chronic diseases; nevertheless, gaps still exist regarding the development process of these mHealth interventions (Dennison et al., 2013). Testing mHealth interventions with patients has revealed preferences and concerns unique to the tested population (Nelson et al., 2016; Sarkar et al., 2016; Steele Gray et al., 2016). Developing a COPD mHealth intervention with insights from COPD patients will potentially improve the process and outcome of the mHealth intervention.

### 4.1.2 Human-Centered Design in Chronic Obstructive Pulmonary Disease

Cruz et al. (2014) conducted a systematic review to provide a comprehensive description of the methodologies used in home telemonitoring interventions for COPD and to explore patients' adherence and satisfaction with the use of telemonitoring systems. They recommended that telemonitoring interventions should be adjusted to their target population and that assessment of patients' acceptance of telemonitoring technology should be considered prior to its implementation (Cruz et al., 2014). Similar strategies can be applied to mHealth. To improve the success of mHealth solutions that target COPD patients, we suggest including COPD patients in the development process. Key lessons about mHealth adoption will be offered as a guide for research and technology developers working with patients with COPD.

## 4.2 Methods

### 4.2.1 Purpose

This study describes the demographics, use, and access to smartphones of patients with COPD. It also aims to explore and develop an understanding of potential facilitators and barriers that might influence COPD patients using mHealth interventions for COPD management.

### 4.2.2 Study Design

We conducted an explanatory sequential mixed methods research design (Creswell, 2015). The study began with a quantitative strand and was followed by a qualitative strand to explain the quantitative results (Creswell, 2015). Explanatory designs are typically chosen when a team anticipates that quantitative measures will not be sufficient to address the research question. They may also be used when quantitative information is required to develop the sample for the qualitative phase (Curry & Nunez-Smith, 2015). In this study, the quantitative component was fully completed before the design and implementation of the qualitative component. The results of the quantitative component were used to define the qualitative sample.

### 4.2.3 Ethical Considerations

Ethical approval for this study was obtained from the Newfoundland and Labrador Health Research Ethics Authority (HREB -2017-194). Before agreeing to participate, all subjects were informed about the nature of the research project, possible risks and benefits, and their rights as research subjects. All participants in the interview completed a written consent form and were given a copy.

### 4.2.4 Quantitative phase

The quantitative phase aimed to describe the demographics, use, and access to smartphones among patients with COPD. It also aimed to assess whether demographic factors predicted engagement with mHealth. The results were used to define the qualitative sample and create the questions required for the qualitative strand.

#### *4.2.4.1 Recruitment and Study Setting*

Participants were recruited during routine visits to their respirologists at outpatient respirology clinics in the Eastern Health Regional Health Authority of the province of

Newfoundland and Labrador (NL), Canada. Participants were eligible for the study if they met the following inclusion criteria:

1. a COPD diagnosis (self-report),
2. aged ≥30 years at study enrollment,
3. able to answer questionnaires in English, and
4. able to provide informed consent.

Patients who attended three respirology clinics received a consent cover letter for research. The cover letter included a questionnaire about technology access and use (Appendix 2). After reading the cover letter, interested participants completed the questionnaire and submitted it in a locked box (blue box) available at the respirology clinic.

The last section of the questionnaire included a question about the participant's interest in participating in an interview regarding the same topic. Interested participants provided their contact information and placed it in another box (red box) located at the respirology clinic.

We separated the contact information from the questionnaire to assure that the questionnaire was kept anonymous. Each questionnaire had a unique identifier. Only the primary investigator (PI) was able to link the questionnaire with the contact information. The sample size (n=100) is comparable to studies conducted by Granger et al. (2018) and Kayyali et al., (2017) who assessed the use of technology among patients. Patients did not receive remuneration for completing the questionnaire.

#### *4.2.4.2 Data Collection*

The questionnaire was adapted from Ramirez et al. (2016) to assess how patients use various types of mobile technology and to what extent they use mHealth. In addition, the questionnaire was used to assess the need for and interest in using mobile health technology, such as mobile phone apps and social media, to help manage health (Ramirez et al., 2016). Similar to Ramirez et al. (2016), the questionnaire was not validated due to the lack of standardized instruments regarding the use and access to mHealth; however, the questions were consistent with previously published literature in the field.

The questionnaire also included demographic information such as age, sex, race/ethnicity, primary language spoken, annual household income, and education level. In addition, participants were asked about their mobile phone ownership and if their mobile phone had internet capabilities. They were also asked if they used the Internet on their mobile phones to learn about their health. Afterwards, the participants were asked about their knowledge of mobile phone apps, if they used such apps, and if they were currently using any mobile health apps. In addition, participants identified individuals who they might rely on to use mobile phones and/or mobile apps for them (e.g., partner, child, friend).

#### *4.2.4.3 Statistical Analysis*

A database of the questionnaire results was created using unique non-identifying numbers. The information was password protected. Before analysis was performed, data were cleaned, coded, and entered into Statistical Package for the Social Sciences (SPSS) version 25.0 (IBM Corp., Armonk, NY). The unclear or incomplete survey items were flagged for queries. These were brought to the attention of the research team, then each item was discussed, and a decision concerning its eligibility and entry was made.

Baseline characteristics of participants were summarized with percentages for categorical variables and means and standard deviations for continuous variables. Crude and adjusted odds ratios were measured using univariate and multivariable logistic regression analyses to determine if smartphone ownership was independently associated with age, sex, marital status, education level, and geographical location. All statistical tests were performed with an alpha significance level of 0.05.

### 4.2.5 Qualitative phase

We used a descriptive qualitative research design grounded in pragmatism (Merriam & Tisdell, 2015; Patton, 2015). Using a qualitative methodology allowed us to achieve an in-depth, contextualized picture of how a diverse sample of patients with COPD think and feel about the possibilities and challenges of using mHealth. This has pragmatic value, as mHealth is an emerging option for delivering healthcare.

#### *4.2.5.1 Recruitment and Study Setting*

Once all the questionnaires were collected and analyzed, we only contacted participants who agreed to participate in an interview. Based on the demographic information collected from the questionnaire, a purposeful sampling strategy was used to identify key informants that could provide rich and diverse interview data. Specifically, we used criterion-based selection (Patton, 2015) to categorize participant characteristics such as age, familiarity with mHealth, smartphone ownership, and years living with COPD.

After interviewing 8 COPD patients, we reached saturation, as we were not gathering new information. However, we continued interviewing until 10 COPD patients were interviewed to strengthen the validity of inferences (Maxwell, 2013). Our final sample size was comparable to similar qualitative studies (Barken et al., 2018; Korpershoek et al., 2018).

The study took place in St. John’s, NL, Canada. We conducted some interviews at Memorial University of Newfoundland and others at the participants’ homes. Participants were recruited from April 2018 to August 2018. After completing the interviews, participants were offered a gift card (30 Canadian dollars).

#### *4.2.5.2 Data Collection*

We conducted individual semi-structured interviews in-person to gain an understanding of the lived experiences of COPD patients in relation to using mHealth (Brinkman & Kvale, 2015; Rubin & Rubin, 2012). Using semi-structured interviews allowed the interviewer to begin with a broad question to direct the focus of the interview and then to provide an opportunity for COPD patients to bring forth their thoughts and feelings about the phenomena they thought were important (Brinkman & Kvale, 2015; Rubin & Rubin, 2012). The interview prompts are available in supplemental Appendix 2. If participants identified that they had not used mHealth, they were asked questions pertaining to why they had not used mHealth (barriers). However, we did not ask them about facilitators because we did not think they had the experience needed to answer these questions. To facilitate discussions, the interviews were conversational in nature, and items were not asked verbatim or in the order presented. As the study progressed, emerging issues were explored with subsequent participants to refine the themes.

The interview questions and prompts were informed by findings from the literature and input from the authors, who have diverse backgrounds including in mHealth, pharmacy, nursing, medicine, respirology, family medicine, education, and qualitative research. They were also informed by interviewing healthcare providers (HCPs) regarding the use of mHealth in COPD management (Alwashmi et al., 2019a). Lastly, the interview questions were informed by the results of the quantitative strand. For example, I was able to explore the barriers further with participants who did not own a smartphone and I was able to learn more about the facilitators from participants who used mHealth intervention to manage their COPD.

The interviews were recorded to enable transparent and accurate transcriptions. Interview lengths ranged from 20 to 40 minutes. Topics included demographics, mHealth usage, perceptions towards challenges of mHealth adoption, factors facilitating mHealth adoption, and preferences regarding features of the mHealth intervention for COPD management. Owing to the large amount of data, preferences regarding features of the mHealth intervention will be published in another article. Data consisted of about four hours of interview time with approximately 100 pages of transcription.

#### *4.2.5.3 Data Analysis*

The interviews were transcribed verbatim and compared against the digital recordings to ensure the accuracy of the content. Identifying information (names) was removed to ensure anonymity. We used NVivo (Version 12; QSR International) to organize the data and examine the words, including frequency counts, as in classical content analysis (Leech & Onwuegbuzie, 2008). All data were analyzed, but we only coded the data that were relevant for answering the research questions, as recommended by Saldana, 2015; Wolcott, 2009; and Yin, 2011. An audit trail was created to keep track of all analytic decisions (Guest et al., 2012).

After using NVivo, we used first cycle coding that was both structural and holistic (Saldaña, 2016), meaning that we used the interview prompts and the literature to guide some of the coding. One researcher analyzed the transcripts and developed a set of themes and sub-themes and then obtained input from a second researcher regarding the validity and accuracy of the chosen themes. In the second cycle of coding, the two researchers independently coded the data using pattern coding to develop themes (Saldaña, 2016). They then discussed commonalities and differences in their coding and theme development until consensus was reached. The analysis of the data was mainly deductive in nature because themes had already been developed using the HCP data, which we used as a starting point (Alwashmi et al., 2019a). An inductive analysis was also performed for new data that did not belong to the existing themes. The iterative process continued as these analyses were conducted to find commonalities, differences, and new patterns in thinking.

### 4.2.6 Mixed methods integration

In addition to the integration at the study design level, we implemented integration at the methods, interpretation, and reporting levels (Fetters et al., 2013). We implemented integration at the methods level in two ways: connecting and building. Connecting occurs when a researcher links one type of data to another type of data through sampling (Fetters et al., 2013). In the present study, we used data from the questionnaire to purposefully sample participants for follow-up interviews. Specifically, we were able to categorize participant characteristics such as age, familiarity with mHealth, smartphone ownership, and years living with COPD. Obtaining information from a diverse group may generate a more complete picture, reveal patterns that would otherwise go unnoticed, and may also help identify novel relationships between variables and concepts (Curry & Nunez-Smith, 2015). Building occurs when one database informs the data collection approach of the other (Fetters et al., 2013). In the present study, we used the questionnaire responses to develop some aspects of the interview guide. This allowed us to potentially gain further insights regarding mHealth use.

Further, we implemented integration at the interpretation and reporting level. We used both integrations through narrative and the use of a joint display (Fetters et al., 2013; Guetterman et al., 2015). Integration through a narrative occurs when a researcher describes the quantitative and qualitative findings in a single report or series of reports (Fetters et al., 2013). In the current study, we describe the findings in a single report and use the contiguous approach, in which qualitative and quantitative findings are reported in different sections. Lastly, we use a joint display to provide a structure to discuss the integrated analysis (Guetterman et al., 2015).

## 4.3 Results

### 4.3.1 A cross-sectional survey of COPD patients

#### *4.3.1.1 Demographics*

A total of 100 adults completed the survey from January 2018 to November 2018. Only 77 participants reported that they were diagnosed with COPD and were included in the analysis. Table 4.1 provides an overview of the demographic and health information of the sample. Of these subjects, 20 (26%) were under the age of 65, 44 (59.5%) were female, and 44/74 (59.5%) were married. Furthermore, 14/52 (26.9%) reported an annual household income of less than $20,000, 52/68 (76.5%) were retired, 48/68 (70.6%) had earned at least a high school diploma, and 20/68 (29.5%) had earned a college or professional degree. Additionally, 18/71 (25.4%) participants were living in a rural area, with a population less than 1,000. The most common comorbidities were cancer 18 (28.1%), diabetes 15 (23.4%), cardiovascular diseases 14 (21.9%), and skeletal or muscular diseases 12 (18.8%). Almost half the participants (28/ 68 , 41.2%) were taking more than six medications.

**Table 4.1:** Participant demographics and health information, n=77.

| **Variable** | | **n(%)** |
|---|---|---|
| Age (years) (n=77) | 30–34 years | 2 (2.6) |
| | 45–54 years | 3 (3.9) |
| | 55–64 years | 15 (19.5) |
| | 65 or older | 57 (74) |
| Sex (n= 74) | Female | 44 (59.5) |
| | Male | 30 (40.5) |

| | | |
|---|---|---|
| Marital status (n=74) | Married | 44 (59.5) |
| | Common Law | 6 (8.1) |
| | Single (never married) | 6 (8.1) |
| | Widowed, Separated, or Divorced | 18 (24.3) |
| Income (n=52) | Under $20,000 | 14 (26.9) |
| | $20,000–$39,000 | 18 (34.6) |
| | $40,000–$59,000 | 6 (11.5) |
| | $60,000–79,000 | 4 (7.7) |
| | $80,000–150,000 | 8 (15.4) |
| | Over $150,000 | 2 (3.8) |
| Employment (n= 68) | Employed full time | 6 (8.8) |
| | Employed part time | 2 (2.9) |
| | Self-employed | 2 (2.9) |
| | Retired | 52 (76.5) |
| | Unemployed | 6 (8.8) |
| Education level (n=68) | Less than high school | 14 (20.6) |
| | High School Equivalency (GED) | 9 (13.2) |
| | High School | 25 (36.8) |
| | College/ trade | 10 (14.7) |
| | Bachelor’s degree | 5 (7.4) |

| | | |
|---|---|---|
| | Master's degree | 4 (5.9) |
| | PhD/ MD/ JD | 1 (1.5) |
| Population size (n=71) | Rural area (with a population less than 1,000) | 18 (25.4) |
| | Small population centre (with a population between 1,000 and 29,999) | 23 (32.4) |
| | Medium population centre (with a population between 30,000 and 99,999) | 6 (8.5) |
| | Large urban population centre (with a population of 100,000 or more). | 24 (33.8) |
| Self reported comorbidities* (n=65) | Cancer | 18 (28.1) |
| | Diabetes | 15 (23.4) |
| | Heart disease | 14 (21.9) |
| | Skeletal/ Muscular disease | 12 (18.8) |
| | Kidney disease | 4 (6.3) |
| | Mental health issues | 2 (3.1) |
| Medication intake (n=68) | None | 2 (2.9) |
| | 1–2 | 10 (14.7) |
| | 3–4 | 12 (17.6) |
| | 4–6 | 16 (23.5) |
| | More than 6 | 28 (41.2) |

* Some patients reported several comorbidities.

#### *4.3.1.2 mHealth technology ownership*

Table 4.2 illustrates the findings regarding mHealth technology ownership. Many participants, 56 (72.7%), owned a mobile phone, but only about a quarter of the participants, 18 (23.4%), owned a smartphone. The number of iPad or tablet owners was slightly higher than smartphones at 25 (32.5%). In terms of the availability of a smartphone in the household, 21 (27.3%) participants stated that a person in the household owns a smartphone. Although only 18 participants reported having a smartphone, 22 (28.6%) participants were able to access the internet via their phone, suggesting a higher number of smartphones than initially reported. About a third of participants (27, 35.1%) owned a blood pressure monitor, and 17 (22.0%) participants owned a glucometer.

**Table 4.2: mHealth technology ownership, n=77.**

| mHealth technology ownership | n(%) |
|---|---|
| Mobile phone | 56 (72.7) |
| Smartphone | 18 (23.4) |
| iPad | 25 (32.5) |
| Availability of a smartphone in the household | 21 (27.3) |
| Internet access through a mobile phone | 22 (28.6) |
| Spirometer/ Peak flow meter | 4 (5.2) |
| Glucometer | 17 (22.0) |
| Blood pressure monitor | 27 (35.1) |
| Heart rate monitor | 10 (13.0) |
| Accelerometer/ activity counter | 3 (3.9) |
| Scale | 15 (19.5) |
| Thermometer | 18 (23.4) |

Logistic regression was performed to ascertain the association of age, sex, marital status, education level, and geographical location with the likelihood that participants owned a smartphone. Due to missing observations, the true N used in the regression is 65/77.

We measured crude odds ratios to determine if smartphone ownership was independently associated with the occurrence of the predictor variables. The likelihood of owning a smartphone was reduced in participants earning less than a high school diploma (crude odds ratio [cOR]= 0.11, 95%CI 0.02–0.64, P-value = 0.014) and participants earning a high school diploma (cOR= 0.14, 95%CI 0.04–0.5, P-value = 0.002) compared to participants who received education beyond high school.

The logistic regression model was statistically significant, $\chi2(7) = 15.77$, $p < .05$. The model explained 30.4% (Nagelkerke R2) of the variance in smartphone ownership and correctly classified 76.9% of cases. Sensitivity was 50.0%, specificity was 88.9%. Of the five predictor variables, only two were statistically significant, and both are related to education level (as shown in Table 4.3). The likelihood of owning a smartphone was reduced in participants earning less than a high school diploma (adjusted odds ratio [aOR]= 0.12, 95%CI 0.017-0.86, P-value = 0.034) and participants earning a high school diploma (aOR= 0.13, 95%CI 0.03–0.54, P-value = 0.005) compared to participants who received education beyond high school.

**Table 4.3**: Logistic regression predicting the likelihood of smartphone ownership

| Variable | | aOR | 95%CI | P value | cOR | 95%CI | P value |
|---|---|---|---|---|---|---|---|
| Age | 30–64 years | 2.24 | 0.57–8.77 | 0.245 | 1.97 | 0.65–6.04 | 0.233 |
| | 65 or older | Ref | | | Ref | | |
| Sex | Female | 2.10 | 0.54–8.19 | 0.285 | 1.03 | 0.36–2.94 | 0.954 |
| | Male | Ref | | | Ref | | |
| Marital Status | In a relationship | 2.36 | 0.494–11.29 | 0.281 | 1.63 | 0.51–5.17 | 0.408 |
| | Not in a relationship | Ref | | | Ref | | |
| Education level | Less than high school | 0.12 | 0.02–0.86 | **0.034*** | 0.11 | 0.02–0.64 | **0.014*** |
| | High school | 0.13 | 0.03–0.54 | **0.005*** | 0.14 | 0.04–0.50 | **0.002*** |
| | More than high school | Ref | | | Ref | | |
| Population size | Rural area | 0.50 | 0.09–2.76 | 0.43 | 0.35 | 0.08–1.47 | 0.149 |
| | Small population center | 0.46 | 0.11–1.92 | 0.29 | 0.61 | 0.19–2.01 | 0.415 |
| | a medium population center or a large population center | Ref | | | Ref | | |

aOR: Adjusted odds ratio; cOR: Crude odds ratio; CI: Confidence Interval
* Significance level is less than 0.05
Note: In a relationship includes being married or in common law; not in a relationship includes being single, widowed, separated, or divorced; high school includes GED.

#### *4.3.1.3 mHealth technology use*

Table 4.4 highlights the findings related to mHealth technology use. Only a third of the participants, 20 (29%), understood the term “app”. Of these, 10 (50%) used apps. Among app users, only three participants used health apps and seven participants were interested in using a health app. Six app users were comfortable allowing their family members to access their health information, and seventy percent were comfortable with their HCP accessing their healthcare information. The most common social media platform used was Facebook (29, 51.8%). Among users of social media, 13/29 (44.8%) reported using social media at least once a day.

Participants completed questions about their concerns regarding mHealth adoption. The first question was about concerns regarding smartphones. The following three options were chosen by participants: cost of smartphones (21, 24.5%), reducing face to face interactions (10, 20.4%) and not easy to use (9, 18.4%). Of the participants who use apps (n=10), the following concerns about app use were chosen: worried about personal information disclosure (6), extra fees to use the app (3), apps use a lot of data (3), apps are not easy to use (1), and I do not know if they are effective (1). No participants chose “taking too much time to use” or “not recommended by a healthcare provider” as a concern arising from using apps.

**Table 4.4:** mHealth technology use.

| Variable | | N | n(%) |
|---|---|---|---|
| Understood the term "app" | | 77 | 20 (29) |
| Use apps | | 20 | 10 (50) |
| Use health apps | | 10 | 3 (30) |
| Interested in using health apps | | 10 | 7 (70) |
| Comfortable allowing a family member to access health information | | 10 | 6 (60) |
| Comfortable allowing a HCP to access health information | | 10 | 7 (70) |
| Social media use | Facebook | 77 | 29 (51.8) |
| | Twitter | 77 | 2 (3.6) |
| | Instagram | 77 | 2 (3.6) |
| | Snapchat | 77 | 1 (1.8) |
| Interested in using social media to share health experience | | 77 | 9 (13.4) |
| Frequency of social media use | Never | 29 | 1 (3.4) |
| | A few times a month | 29 | 5 (17.2) |
| | A few times a week | 29 | 3 (10.3) |
| | About once a day | 29 | 7 (24.1) |
| | More than once a day | 29 | 13 (44.8) |

n= 77 is the total study population.
n= 20 is the sample who understood the term "app".
n= 10 is the sample that use apps.
n= 29 is the sample that use social media.

### 4.3.2 Semi-structured Interviews with COPD patients

We developed themes under two categories: facilitators and barriers that would influence the feasibility and use of mHealth. We have included details and examples to illustrate the patients' thoughts and beliefs.

#### *4.3.2.1 Demographics*

Ten COPD patients participated in face-to-face interviews. The mean age was 67.6 (±7.58) years and the range was from 51–80 years. There were four females and six males. Participants stated that the mean number of years living with COPD was 8.4 (±4.45) and the range was from 3–15 years.

Six participants owned a smartphone, two owned a mobile phone, and two did not have either. Participants used their phones for different purposes, including communication, managing finances, gaming, and browsing the internet. One patient stated "I use it for everything. I never thought I'd see the day where I was dependant on my phone". On the other hand, another participant stated that she did not use her smartphone beyond making phone calls: "I have a phone but I am not smart enough to use it". Some participants used it to monitor their physical activity: "I have a health thing on it and I look at it every once in a while just to see how many steps I've done that day because it… Improve health activity". One patient used his smartphone to "get pollen reports and anything that will trigger a COPD attack...to do research on nutraceutical products or on COPD-related matters". Four participants were enrolled in an mHealth intervention to manage their COPD.

#### *4.3.2.2 Facilitators*

Patients reported four facilitators, which are discussed below.

**1. There are possible health benefits for patients.**

Patients agreed that mHealth has the potential to provide health benefits to patients. Some patients mentioned that mHealth could increase patient autonomy by providing empowerment and motivation to patients. One patient who used a fitness tracker remarked, "I think it's better for me to track what I do every day. It is going to make me feel better...That would help me a lot with my pains… I know how my day was and I know how I feel like". Another patient who kept track of his vitals, weight, and medication intake stated that "if I had been monitored, I might not have this broken arm...That should've been picked up on. I mean, I got the records there and you look back on it, I can easily look back on them now and say you had water retention, your resting heart rate was way too high, and your blood pressure was low. There's something wrong". Two patients described that mHealth could provide a sense of security and reduce hospitalization: "...it felt good to have that, you know, that security there at least that in those four months that I had it. So there was no guessing because you don't know if you should or you shouldn't go to a hospital."

**2. The software needs to be easy to use.**

Usability was highlighted by many patients as an important factor in increasing the uptake of mHealth. One patient cautioned that he might not use an intervention if it was not easy to use: "I'm not getting into something that's going to fill up my day ferreting around. But if it's something that I've got to look at for five or ten minutes, I'm okay with that". Participants who were enrolled in an mHealth intervention mentioned that there was “no trouble setting up. It’s all there, so all you had to do is turn it on”.

**3. Patients need to be educated on the use of mHealth.**

Patients learned how to use mHealth interventions via different sources. The majority asked their family members for assistance “...I’ll go to my 14-year-old who is generationally more apt to be able to teach me a new technology”. This was also mentioned by another patient who used a fitness tracker: “My nieces. They buy it for me and they set it up for me and everything”. Other patients taught themselves about mHealth interventions: “If I can read it, I can learn it...I generally research it myself” or used the library: “Also the libraries here will help you in any programs”. One patient said that her “...own care worker helps with it, I don’t know how to do it”. It was also recommended by some that technical support staff be available as a resource for patients to call when they needed technical help.

**4. The credibility of mHealth needs to be evident.**

Some patients thought that the credibility of mHealth needs to be made evident. Some patients stated that they would use an mHealth intervention if it was recommended by their HCP: “if he told me that, I probably would try to do it”. This was reiterated by a patient who monitored his COPD regularly: “Doctor xx was the one that said to me… If you’re going to cope with this and keep it under control, you’re going to have to learn how to look after yourself”.

#### *4.3.2.3 Barriers*

Patients reported six barriers to mHealth adoption, which are discussed below.

**1. There are technical issues with mHealth.**

A few patients expressed that they did not have the technical expertise to use mHealth. One patient expressed his concern: “I wouldn’t know how to turn a computer on. I’m not very good… You know, I never grew up with computers but I have seen one”. This was reiterated by another patient: “It just looked way too complicated to download the app so I didn’t because I’m technology averse”. For patients that used mHealth, technical issues included limited cellular and Wifi connection: “we travel out to the cabin every weekend and the cabin’s out in central Newfoundland out in Terra Nova and now it’s getting better now because these phone services getting better out there”. Another issue was moving and setting up the mHealth intervention components, such as a blood pressure monitor or a scale, when travelling: “... it’s not a problem. But when you go on vacation, sometimes you got to take this along with you and set it up somewhere”.

**2. Lack of awareness is a challenge.**

Many patients indicated that a lack of awareness is a barrier to mHealth adoption. One patient expressed this concern: “I’m not aware of everything that’s out there, but people need to be more aware of their COPD and know more about it.” Also, a family member stated the following about her mother who has COPD: “I think it’s more she probably don’t know what her phone can do, right. But if you say to her okay we’re going to start using this, this is going to be useful and it’s going to be beneficial I’m sure she’d be game for it”.

However, patients who participated in an mHealth intervention stated that their HCP recommended the mHealth intervention to them when they were in the hospital or attended a community health event. Another patient mentioned that “it was advertised and I called in about it and they got in contact with me, set me up with it”.

**3. There may be limited uptake from the elderly.**

A few patients mentioned that they face issues in adopting technology because of their age. One patient stated, "I'm not generationally born into technology that is prevalent and considered a norm of the day". This was also mentioned by another: "I try but I'm a little bit nervous, sometimes I'll ask my daughter or someone else around because we didn't grow up with the phones as you do today".

**4. There are possible financial barriers.**

A few patients said they cannot afford mHealth and did not have access to smartphones. One patient expressed it this way: "there's no way I'll pay that money". Expenses incurred through the use of data were also discussed: "it's a bit expensive for like I've got no data right now because it's all extra". In addition to individual patient costs, one patient raised the concern of additional costs required by HCPs: "doctors are not going to do that without a fee". Also, some mHealth programs are limited to a certain period, so this may increase costs.

**5. There may be privacy and confidentiality concerns.**

One patient thought privacy and confidentiality could be a barrier to mHealth adoption. She was open to sharing the results with a HCP but not a family member: "I don't want to make them worry (her family) because I told them nothing about my cancer... I don't like to worry my family". The rest of the patients were willing to share the results with their family members and HCPs: "I don't care who sees it...They can put it in the Evening Telegram, doesn't bother me." This was echoed by another patient: "they (his family) watch over my shoulder like nothing else now".

**6. Some patients were not interested in using an mHealth intervention.**

Some patients indicated that a lack of interest in mHealth is a major barrier to its adoption. One patient expressed this concern: “I do try to help myself but when it comes to using the phone and that stuff and the computer, it’s not for me”. This was also mentioned by another patient with limited technology experience: “I know on smartphones you can dial, you can play a game and some they can even watch movies probably, but I got no interest”. Another patient mentioned that they are too busy to include an mHealth intervention in their routine: “So my day is pretty filled with different things. So remembering is a problem. Sometimes I just say: To hell with it and I am not going to do it. But remembering is probably the biggest thing”.

When patients use mHealth, they may not share the results with their HCP. This occurs if the mHealth intervention is not integrated in the healthcare system. One patient posited that some HCPs are not interested in reviewing the records brought by patients: “And my sheet, he didn’t even look at it...That’s, that’s depressing”.

## 4.4 Discussion

### 4.4.1 Principal Findings

We conducted an explanatory sequential mixed methods study with COPD patients and identified their perceptions regarding the use of mHealth for COPD management. The quantitative component revealed that over 70% of COPD patients owned a mobile phone, but only about a quarter of the participants, 18/77 (23.4%), owned a smartphone. The likelihood of owning a smartphone was not associated with age, sex, marital status, or geographical location. However, patients with high educational status were more likely to own a smartphone. The qualitative component found that COPD patients, in general, had a positive attitude toward mHealth adoption for COPD management, but several facilitators and barriers were identified. It is important to promote the facilitators and address the barriers to optimize the successful implementation of mHealth interventions.

Using a mixed methods approach allowed us to produce a diverse sample of COPD patients. The quantitative and qualitative components complemented each other to improve the validity of inferences and expand on why participants answered quantitative questions in a certain way. For example, the number of participants who stated that they had a smartphone (n=18) was lower than the number of participants who accessed the internet through their mobile phone (n=22), suggesting a lack of understanding of what a smartphone is. This was explored further during the interviews. Although some participants owned a smartphone, their use was limited to making phone calls and taking pictures. On the other hand, some participants did not own a smartphone, but they were able to enrol in an mHealth intervention and complete the program. As explained by one patient, “Eastern Health sets you up with everything. It’s so different, there’s nothing to it, it’s just hit the button, use your device and it’s so easy to use”. This finding highlights the need for education and confidence building among patients with COPD.

We created a joint display (Table 4.5) to clarify some of the barriers that were reported quantitatively. The table is organized by survey items. It merges the related quantitative results and provides typical comments from COPD patients.

**Table 4.5:** Joint display about barriers to mHealth adoption

| **Quantitative Results** | | | **Qualitative Results** | **Interpretation of mixed methods findings** |
|---|---|---|---|---|
| Variable | | n/ % | Exemplar Quotes | |
| Concerns regarding smartphones (N=77) | Cost of smartphones | 21/ 27.3 | "I can't afford one (smartphone)";<br>"I've got no data right now because it's all extra"; "we can always get one (smartphone)". | Costs include the cost of a smartphone and the data to enable its functionalities. However, some patients could not afford to get a smartphone, or it could be provided by the healthcare system. |
| | Not easy to use | 9/ 11.7 | "I wouldn't know how to turn a computer on. I'm not very good…"<br><br>"There's nothing to it, it's just hit the button, use your device and it's so easy to use". | Although some participants owned a smartphone, their use was limited to making phone calls and taking pictures. On the other hand, some participants did not own a smartphone, but they were able to enrol in an mHealth intervention and complete the program. This finding highlights the need for education and confidence building among patients with COPD. |
| Concerns regarding app use (N=10) | Worried about personal information disclosure | 6/ 60 | "I don't want to make them worry because I told them nothing about my cancer... I just told my sister a week before I had my surgery... I don't like to worry my family".<br><br>"I don't care who sees it...They can put it in the Evening Telegram, doesn't bother me". | There was inconclusive evidence regarding confidentiality. Patients should have a choice in what to share and who should have access to their health information. |

n= 77 is the total study population.
n= 10 is the sample that use apps.

### 4.4.2 Comparison with Prior Work

Our study provides a meaningful contribution to the literature, as few prior studies have specifically examined the use of mHealth among COPD patients. It is important to note that the published literature on mHealth access and use was focused on general, and largely healthy, populations, with little attention to individuals with chronic illnesses, such as COPD (Robbins et al., 2017).

A study investigated smartphone ownership among the general public and reported a high smartphone adoption rate, 76% (Kayyali et al., 2017). Ramirez et al. (2016) investigated smartphone ownership in primary care clinics and also found a high adoption rate of 76%; however, 96% of the participants were younger than 65 years old. Among COPD patients from several locations in the US, we found lower smartphone adoption rates, 47%, which was double the rate reported in our sample (Witry et al., 2018). The qualitative data expand on this finding by clarifying that some smartphone owners use their device in ways similar to a mobile phone owner. Knowing how to use the features of a smartphone, such as using apps, is necessary for using the mHealth intervention. This finding highlights the need for education and confidence building among some smartphone users to help them use their devices for COPD management.

Our logistic regression results support the claim that a lower level of education is associated with limited access to mobile devices (Krebs & Duncan, 2015; Fox & Duggan, 2012; Illiger et al., 2014). Other researchers also found that the individuals more likely to use health apps tended to be younger and have higher incomes (Krebs & Duncan, 2015; Witry et al., 2018; Fox & Duggan, 2012; Illiger et al., 2014). Our findings echo concerns about the relationship between mHealth access and health disparities (Witry et al., 2018). Limiting mHealth interventions to smartphone or tablet owners could disproportionately benefit highly educated and wealthy individuals.

We also investigated the association between technology use and geographical location. Although we did not find differences between smartphone ownership among urban and rural patients with COPD, a report suggests that individuals living in rural areas are less likely than nonrural adults to have smartphones (Perrin, 2017). Previous studies suggest that among patients with COPD, living in rural areas was associated with worse health status (Abrams et al., 2013; Jackson et al., 2013). The authors suggest that the higher prevalence of COPD in rural areas could be linked to an increased proportion of older residents, a shortage of HCPs, the underusage of spirometry and pulmonary rehabilitation, and problems with access to medical care (Abrams et al., 2013; Jackson et al., 2013). Limited access to smartphones may further exacerbate health disparities for rural COPD patients (Witry et al., 2018). Policy makers and researchers should consider providing access to technologies for patients that cannot afford it. Additionally, some technology recycling programs may assist in the bridging the digital divide.

Similar to Kayyali et al. (2017), the majority of the participants were open to data sharing options with a HCP through mHealth apps. Nevertheless, Kayyali et al. (2017) stated that data sharing can be ineffective if the participant is not honest or if data sharing is overused.

Some of the findings presented in this study confirm previously reported findings in the context of mHealth for COPD management. Our findings are in agreement with Vorrink et al. (2017), who stress the importance of training patients and HCPs on the proper use of mHealth. As suggested by Korpershoek et al. (2018), we confirm that the expected benefits of using mHealth contribute to the success of mHealth uptake, and our study provides additional insight regarding these perceptions, such as on the ease of use, educating patients about mHealth, and the importance of credibility. Our findings echo some and add to the barriers reported by Krebs

& Duncan (2015), which include technical difficulties and a lack of interest. We included quotes from participants to expand on these insights.

In comparison with the facilitators reported by HCPs, patients had four parallel facilitators: there are possible health benefits for patients, the software needs to be easy to use, patients need to be educated on the use of mHealth, and the credibility of mHealth should be evident (Alwashmi et al., 2019a). The only facilitator that was not mentioned by patients is that mHealth should reduce the cost to the healthcare system. On the other hand, patients had five parallel barriers with the HCPs: there are technical issues with mHealth, lack of awareness is a challenge, there may be limited uptake from the elderly, there are possible financial barriers, and there may be privacy and confidentiality concerns (Alwashmi et al., 2019a). The possibility of mHealth limiting the personal connection between HCPs and patients was not mentioned as a barrier by patients. Furthermore, one new barrier emerged from interviewing patients: some patients were not interested in using mHealth interventions. Our findings, and the limited literature on the matter, emphasize the need for further research into the use of mHealth in COPD management.

### 4.4.3 Strengths and Limitations

This study has several strengths. First, we used a mixed methods approach to produce a diverse sample of participants. This human-centered approach ensures that the needs and challenges of a diverse group of COPD patients can be considered prior to developing an mHealth intervention. Second, some COPD patients had experience in using an mHealth intervention to manage their COPD, which further increases the richness of the data. Third, all the interviews were conducted in a similar manner to ensure consistency during the data collection and analysis. Fourth, mHealth is particularly important in geographic locations with a relatively large proportion of rural residents such as Newfoundland and Labrador (NL). Of the Atlantic Provinces, NL has the highest proportion of its population (60%) living in rural areas (Simms & Greenwood, 2015). mHealth may enhance care provider access throughout sparsely populated rural areas. NL has a substantial remote and rural population; therefore, our results may be more applicable to rural areas. Lastly, we recruited COPD patients from outpatient respirology clinics. This has led to capturing a well-characterized cohort of individuals with COPD.

There were also several limitations. First, the number of COPD patients who completed the survey was fairly small. However, all efforts were made to recruit as many participants as possible and facilitate the completion of the survey. Due to the small sample size, regression coefficients may have been imprecisely estimated. However, the age of the sample was reflective of a representative sample of COPD patients in Canada that were recruited from a respirology clinic (Safka et al., 2017). Second, not all the patients had experience with using mHealth. Thus, the perceptions of these participants were not based on actual interventions with patients. Third, conducting focus groups with some of the participants following the individual interviews could have yielded richer information, as participants would have been given the opportunity to compare their thoughts and confirm or expand upon each other's ideas. Fourth, there were no questions in the quantitative survey about facilitators of mHealth uptake. Including this topic would have been beneficial, as it could have been expanded upon when conducting the interviews.

### 4.4.4 Implications for practice and for future research

The findings of this study may help various stakeholders who are planning to use mHealth interventions for COPD management. Some of the barriers and facilitators have the potential to be applied to other chronic diseases. It is important to consider the low rate of smartphone use among COPD patients when implementing an mHealth intervention for COPD management. Some lessons learned include the importance of raising awareness among COPD patients regarding the potential of mHealth interventions in COPD management. Family members could play a significant role in raising awareness as well as in teaching patients with COPD about mHealth. The findings also stress the importance of developing a user-friendly mHealth intervention. This could reduce the time and resources required to teach patients about the mHealth intervention. The lack of an internet connection could limit access to mHealth interventions. This should be taken into consideration when measuring access to health resources in rural communities.

Future studies would benefit from conducting focus groups with some of the participants following the individual interviews. Focus groups could yield rich information, as participants would be given the opportunity to compare their thoughts and confirm or expand upon each other's ideas. After developing a user-centred mHealth intervention, the authors recommend using a mixed methods framework for usability testing (Alwashmi et al., 2019b). Additional trials will be required to provide data regarding the efficacy and cost-effectiveness of mHealth interventions in COPD management.

## 4.5 Conclusion

It is important to understand access to mHealth among patients with COPD and their perceptions regarding the adoption of mHealth for COPD management. Despite the rise in smartphone adoption, the rate among patients with COPD remains low. Additionally, it is important to consider that owning a smartphone does not mean one has the ability to use it for mHealth. This finding highlights the need for education and confidence building among some smartphone users to be able to use their devices for COPD management. This study identifies some potential facilitators and barriers that may inform the successful development and implementation of mHealth interventions for COPD management. We recommend that those who develop mHealth interventions for COPD should consider the facilitators and barriers highlighted in this study.

## 4.6 References

Abrams, T. E., Vaughan-Sarrazin, M., Fan, V. S., & Kaboli, P. J. (2011). Geographic isolation and the risk for chronic obstructive pulmonary disease–related mortality: A cohort study. Annals of internal medicine, 155(2), 80-86.

Alwashmi, M. F., Fitzpatrick, B., Davis, E., Gamble, J. M., Farrell, J., & Hawboldt, J. (2019a). Perceptions of Health Care Providers Regarding a Mobile Health Intervention to Manage Chronic Obstructive Pulmonary Disease: Qualitative Study. JMIR mHealth and uHealth, 7(6), e13950.

Alwashmi, M. F., Hawboldt, J., Davis, E., & Fetters, M. D. (2019b). The Iterative Convergent Design for Mobile Health Usability Testing: Mixed-Methods Approach. JMIR mHealth and uHealth, 7(4), e11656.

Alwashmi, M., Hawboldt, J., Davis, E., Marra, C., Gamble, J., & Abu Ashour, W. (2016). The effect of smartphone interventions on patients with chronic obstructive pulmonary disease exacerbations: A systematic review and meta-analysis. JMIR mHealth and uHealth, 4(3), e105. doi:10.2196/mhealth.5921

Barken, T. L., Thygesen, E., & Söderhamn, U. (2018). Unlocking the limitations: Living with chronic obstructive pulmonary disease and receiving care through telemedicine—A phenomenological study. Journal of clinical nursing, 27(1-2), 132-142.

Bender, B. (2014). Nonadherence in chronic obstructive pulmonary disease patients: What do we know and what should we do next? Current Opinion in Pulmonary Medicine, 20(2), 132-137. doi:10.1097/MCP.0000000000000027

Boyd, C. M., & Fortin, M. (2010). Future of multimorbidity research: How should understanding of multimorbidity inform health system design? Public Health Reviews, 32(2), 451-474. doi:10.1007/BF03391611

Brinkman, S., & Kvale, S. (2015). Interviews: Learning the craft of qualitative research interviewing (3rd ed.). Los Angeles: Sage.

Canadian Institute for Health Information. (2008). Health indicators.http://www.webcitation.org/76gVKOWKJ

Chiang, Kuei-Feng|Wang, Hsiu-Hung|Chien, I.-Kuang|Liou, Jhao-Kun|Hung, Chung-Lieh|Huang, Chien-Min|Yang, Feng-Yueh. (2015). Healthcare providers' perceptions of barriers in implementing of home telecare in taiwan: A qualitative study. International Journal of Medical Informatics, 84(4), 277-287. doi:10.1016/j.ijmedinf.2015.01.007

Creswell, J. W. (2016). 30 essential skills for the qualitative researcher. Los Angeles ; London; New Delhi ; Singapore ; Washington DC: Sage.

Creswell, J. W. (2015). A concise introduction to mixed methods research. Sage Publications.

Cruz, Joana|Brooks, Dina|Marques, Alda. (2014). Home telemonitoring in COPD: A systematic review of methodologies and patients' adherence. International Journal of Medical Informatics, 83(4), 249-263. doi:10.1016/j.ijmedinf.2014.01.008

Curry, L., & Nunez-Smith, M. (2015). Mixed methods in health sciences research: A practical primer (Vol. 1). Sage Publications.

Damhus, C. S., Emme, C., & Hansen, H. (2018). Barriers and enablers of COPD telerehabilitation - a frontline staff perspective. International Journal of Chronic Obstructive Pulmonary Disease, 13, 2473-2482. doi:10.2147/COPD.S167501

Dennison, L., Morrison, L., Conway, G., & Yardley, L. (2013). Opportunities and challenges for smartphone applications in supporting health behavior change: Qualitative study. Journal of Medical Internet Research, 15(4), e86. doi:10.2196/jmir.2583

DiDonato, K. L., Liu, Y., Lindsey, C. C., Hartwig, D. M., & Stoner, S. C. (2015). Community pharmacy patient perceptions of a pharmacy-initiated mobile technology app to improve adherence. International Journal of Pharmacy Practice, 23(5), 309-319. doi:10.1111/ijpp.12168

Emerson, R. W. (2015). Convenience sampling, random sampling, and snowball sampling: How does sampling affect the validity of research? Journal of Visual Impairment & Blindness, 109(2), 164-168. doi:10.1177/0145482X1510900215

Fetters M. D., Curry L. A., Creswell J. W. (2013). Achieving integration in mixed methods designs principles and practices. Health Services Research, 48, 2134-2156.

Fox S, Duggan M. Pew Research Center. Washington, DC: Pew Internet & American Life Project; 2012 Nov 08. Mobile health 2012 URL: http://www.pewinternet.org/2012/11/08/mobile-health-2012/ [accessed 2015-04-23] [WebCite Cache]

Granger, C. L., Wijayarathna, R., Suh, E. S., Arbane, G., Denehy, L., Murphy, P., & Hart, N. (2018). Uptake of telehealth implementation for COPD patients in a high-poverty, inner-city environment: A survey. Chronic respiratory disease, 15(1), 81-84.

Guest, G., MacQueen, K. M., & Namey, E. E. (2012). Applied thematic analysis. Los Angeles: Sage.

Guetterman, T. C., Fetters, M. D., & Creswell, J. W. (2015). Integrating quantitative and qualitative results in health science mixed methods research through joint displays. The Annals of Family Medicine, 13(6), 554-561.

Health Level Seven. (2018). Mobile health http://www.hl7.org/Special/committees/mobile/index.cfm

Heffernan, K. J., Chang, S., Maclean, S. T., Callegari, E. T., Garland, S. M., Reavley, N. J., et al. (2016). Guidelines and recommendations for developing interactive eHealth apps for complex messaging in health promotion. JMIR mHealth and uHealth, 4(1), e14. doi:10.2196/mhealth.4423

Illiger, K., Hupka, M., von Jan, U., Wichelhaus, D., & Albrecht, U. V. (2014). Mobile technologies: expectancy, usage, and acceptance of clinical staff and patients at a university medical center. JMIR mHealth and uHealth, 2(4), e42.

International Organization for Standardization, (ISO). (2010). Ergonomics of human-system interaction - part 210: Human-centred design for interactive systems (ISO 9241-210:2010)

Jackson, B. E., Coultas, D. B., Suzuki, S., Singh, K. P., & Bae, S. (2013). Rural-Urban Disparities in Quality of Life Among Patients With COPD. The Journal of Rural Health, 29(s1), s62-s69.

Jo, S., & Park, H. (2016). Development and evaluation of a smartphone application for managing gestational diabetes mellitus. Healthcare Informatics Research, 22(1), 11-21. doi:10.4258/hir.2016.22.1.11

Joe, J., & Demiris, G. (2013). Older adults and mobile phones for health: A review. Journal of Biomedical Informatics, 46(5), 947-954. doi:10.1016/j.jbi.2013.06.008

Juen, J., Qian Cheng, & Schatz, B. (2015). A natural walking monitor for pulmonary patients using mobile phones. IEEE Journal of Biomedical and Health Informatics, 19(4), 1399-1405. doi:10.1109/JBHI.2015.2427511

Kayyali, R., Peletidi, A., Ismail, M., Hashim, Z., Bandeira, P., & Bonnah, J. (2017). Awareness and use of mHealth apps: a study from England. Pharmacy, 5(2), 33.

Korpershoek, Y. J. G., Vervoort, S. C. J. M, Trappenburg, J. C. A., & Schuurmans, M. J. (2018). Perceptions of patients with chronic obstructive pulmonary disease and their health care providers towards using mHealth for self-management of exacerbations: A qualitative study. BMC Health Services Research, 18(1), 1-13. doi:10.1186/s12913-018-3545-4

Krebs, P., & Duncan, D. T. (2015). Health app use among US mobile phone owners: a national survey. JMIR mHealth and uHealth, 3(4), e101.

Leech, N. L., & Onwuegbuzie, A. J. (2008). Qualitative data analysis: A compendium of techniques and a framework for selection for school psychology research and beyond. School psychology quarterly, 23(4), 587.

Lisa Brunton, Peter Bower, & Caroline Sanders. (2015). The contradictions of telehealth user experience in chronic obstructive pulmonary disease (COPD): A qualitative meta-synthesis. PLoS One, 10(10), e0139561. doi:10.1371/journal.pone.0139561

Macdonald, G. G., Townsend, A. F., Adam, P., Li, L. C., Kerr, S., McDonald, M., et al. (2018). eHealth technologies, multimorbidity, and the office visit: Qualitative interview study on the perspectives of physicians and nurses. Journal of Medical Internet Research, 20(1), e31. doi:10.2196/jmir.8983

Maxwell, J. A. (2013). Qualitative research design (3. ed. ed.). Los Angeles [u.a.]: Sage.

Mehdi Najafzadeh, Carlo A Marra, Larry D Lynd, Mohsen Sadatsafavi, J Mark FitzGerald, Bruce McManus, et al. (2012). Future impact of various interventions on the burden of COPD in Canada: A dynamic population model. PLoS One, 7(10), e46746. doi:10.1371/journal.pone.0046746

Merriam, S. B., & Tisdell, E. J. (2015). Qualitative research (Fourth edition. ed.). US: Jossey-Bass.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). Qualitative data analysis. Los Angeles, Calif: Sage.

Murray, C. J., & Lopez, A. D. (1997). Alternative projections of mortality and disability by cause 1990–2020: Global burden of disease study. The Lancet, 349(9064), 1498-1504. doi:10.1016/S0140-6736(96)07492-2

Nelson, L. A., Mayberry, L. S., Wallston, K., Kripalani, S., Bergner, E. M., & Osborn, C. Y. (2016). Development and usability of REACH: A tailored theory-based text messaging intervention for disadvantaged adults with type 2 diabetes. JMIR Human Factors, 3(2), e23. doi:10.2196/humanfactors.6029

Patton, M. Q. (2015). Qualitative research & evaluation methods: Integrating theory and practice Sage Publications.

Perrin, A. (2017). Digital gap between rural and nonrural America persists. Pew Research Center.

Robbins, R., Krebs, P., Jagannathan, R., Jean-Louis, G., & Duncan, D. T. (2017). Health app use among US mobile phone users: analysis of trends by chronic disease status. JMIR mHealth and uHealth, 5(12), e197.

Rubin, H. J., & Rubin, I. S. (2012). Qualitative interviewing: The art of hearing data (Third edition ed.). Los Angeles: Sage.

Safka, K. A., Wald, J., Wang, H., McIvor, L., & McIvor, A. (2017). Gold stage and treatment in COPD: a 500 patient point prevalence study. Chronic Obstructive Pulmonary Diseases: Journal of the COPD Foundation, 4(1), 45.

Saldaña, J. (2016). The coding manual for qualitative researchers (3E [3th edition] ed.). Los Angeles ; London ; New Delhi ; Singapore ; Washington, DC: SAGE.

Sarkar, U., Gourley, G., Lyles, C., Tieu, L., Clarity, C., Newmark, L., et al. (2016). Usability of commercially available mobile applications for diverse patients. Journal of General Internal Medicine, 31(12), 1417-1426. doi:10.1007/s11606-016-3771-6

Simms, A., & Greenwood, R. (2015). Newfoundland and Labrador. State of Rural Canada Report, 73.

Smith, S. A., Claridy, M. D., Smith Whitehead, M., Sheats, J. Q., Yoo, W., Alema-Mensah, E. A., et al. (2015). Lifestyle modification experiences of African American breast cancer survivors: A needs assessment. JMIR Cancer, 1(2), e9. doi:10.2196/cancer.4892

Steele Gray, C., Khan, A. I., Kuluski, K., McKillop, I., Sharpe, S., Bierman, A. S., et al. (2016). Improving patient experience and primary care quality for patients with complex chronic disease using the electronic patient-reported outcomes tool: Adopting qualitative methods into a user-centered design approach. JMIR Research Protocols, 5(1), e28. doi:10.2196/resprot.5204

Steinhubl, S. R., Muse, E. D., & Topol, E. J. (2015). The emerging field of mobile health. Science Translational Medicine, 7(283), 283rv3.

Theriault L, Hermus G, Goldfarb D, Stonebridge C, Bounajm F. (2012). Cost risk analysis for chronic lung disease in Canada. Retrieved http://www.conferenceboard.ca/e-library/abstract.aspx?did=4585

Vogelmeier, C. F., Criner, G. J., Martinez, F. J., Anzueto, A., Barnes, P. J., Bourbeau, J., ... & Frith, P. (2017). Global strategy for the diagnosis, management, and prevention of chronic obstructive lung disease 2017 report. GOLD executive summary. American journal of respiratory and critical care medicine, 195(5), 557-582.

Vorrink, S., Huisman, C., Kort, H. H., Troosters, T., & Lammers, J. J. (2017). Perceptions of patients with chronic obstructive pulmonary disease and their physiotherapists regarding the use of an eHealth intervention. JMIR Human Factors, 4(3), e20. doi:10.2196/humanfactors.7196

Vorrink, S., Kort, H. H., Troosters, T., & Lammers, J. J. (2016). A mobile phone app to stimulate daily physical activity in patients with chronic obstructive pulmonary disease: Development, feasibility, and pilot studies. JMIR Mhealth and Uhealth, 4(1), 156. doi:10.2196/mhealth.4741

Witry, M., Comellas, A., Simmering, J., & Polgreen, P. (2018). The Association between Technology Use and Health Status in a Chronic Obstructive Pulmonary Disease Cohort: Multi-Method Study. Journal of medical Internet research, 20(4), e125.

Wolcott, H. F. (2008). Writing up qualitative research. Sage Publications.

Yin, R. K. (2011). Qualitative research from start to finish. New York, NY.

Zhang, J., Song, Y., & Bai, C. (2013). MIOTIC study: A prospective, multicenter, randomized study to evaluate the long-term efficacy of mobile phone-based internet of things in the management of patients with stable COPD. International Journal of Chronic Obstructive Pulmonary Disease, 8, 433-438. doi:10.2147/COPD.S50205

# Chapter 5: Features of a Mobile Health Intervention to Manage Chronic Obstructive Pulmonary Disease: Qualitative Study

## Preface

A version of this chapter will be submitted to a suitable journal. I completed the first draft and revised it according to the suggestions of co-authors and reviewers. Dr. John Hawboldt and Dr. Erin Davis suggested the general research topic and provided feedback on the manuscript. Dr. Beverly Fitzpatrick helped revise the original manuscript to make the argument clearer. Dr. Jamie Farrell, Gerard Farrell, Hai Nguyen and Dr. John-Michael Gamble reviewed the manuscript and provided revision suggestions. Dr. Jamie Farrell also assisted in recruiting participants.

## Abstract

**Background:** The use of mobile health (mHealth) interventions has the potential to enhance chronic obstructive pulmonary disease (COPD) treatment outcomes. Further research is needed to determine which mHealth features are required to potentially enhance COPD self-management.

**Objective:** The aim of this study was to explore the potential components of an mHealth intervention for COPD management with health care providers (HCPs) and patients with COPD.

**Methods:** This was a qualitative study. We conducted semistructured individual interviews with HCPs, including nurses, pharmacists, and physicians who work directly with patients with COPD. Interviews were also conducted with a diverse sample of patients with COPD. A guide with prompts was used to facilitate discussions. Interview topics included demographics, mHealth usage, the potential use of medical devices, and recommendations for features that would enhance an mHealth intervention for COPD management. Interviews were conversational in nature, and the items were not asked verbatim or in the order presented.

**Results:** A total of 40 people — patients, nurses, physicians, and pharmacists — participated. The main recommendations for the proposed mHealth intervention were categorized into two categories: patient interface and HCP interface. The prevalent features suggested for the patient interface include educating patients, collecting baseline data, collecting subjective data, collecting objective data via compatible medical devices, providing a digital action plan, allowing patients to track their progress, enabling family members to access the mHealth intervention, tailoring the features based on the patient's unique needs, reminding patients about critical management tasks, and rewarding patients for their positive behaviors. The most common features of the HCP interface include allowing HCPs to track their patients' progress, allowing HCPs to communicate with their patients, educating HCPs and remunerating HCPs.

**Conclusions:** It is important to understand the perceptions of patients and HCPs regarding the adoption of innovative mHealth interventions for COPD management so that the most effective, efficient, and feasible mHealth intervention can be developed to improve patient health. This study identifies important potential features that may inform the successful development and implementation of mHealth interventions for COPD management.

## 5.1 Introduction

The significant rise in mobile phone ownership coupled with increased expectations of the user's role in managing their own care presents a unique opportunity for Mobile Health (mHealth) interventions (Mendiola et al., 2015). The Global Observatory for eHealth of the World Health Organization defines mHealth as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants, and other wireless devices" (World Health Organization, 2011). A mobile mHealth intervention could also include the use of a medical device that is compatible with a smartphone. The literature suggests that mHealth interventions could play a significant role in the management of chronic health conditions, including chronic obstructive pulmonary disease (COPD) (Alwashmi et al., 2016; Joe & Demiris, 2013; Juen et al. 2015; Zhang, Song, & Bai, 2013). Alwashmi et al. noted that the current literature on the role of smartphones in reducing COPD exacerbations is limited, but it suggests that smartphone interventions may reduce COPD exacerbations (2016).

### 5.1.1 Chronic Obstructive Pulmonary Disease Treatment and Management

Effective COPD management could delay disease progression and reduce acute exacerbations, thereby improving patients' quality of life and reducing healthcare costs (Nguyen et al., 2009). There are various methods for enhancing COPD management. Smoking cessation is the most important factor that influences the natural history of COPD (GOLD, 2019). Patient education regarding the disease and correct use of inhalers is also vital for COPD management. Lareau and Hodder stress the importance of patient education for the correct use of inhalers to ensure the effectiveness of inhaled medications (Lareau & Hodder, 2012). In addition, the synergistic effects of multiple COPD interventions, such as pulmonary rehabilitation, oxygen supplementation, and physical activity, could enhance COPD management. Physical activity is beneficial for patients with COPD, and they should repeatedly be encouraged to remain active

(GOLD, 2019). Various studies reported that pulmonary rehabilitation (Burkow et al., 2015) and physical activity interventions can be delivered remotely (Nguyen et al., 2009).

Both pharmacological and non-pharmacological management strategies are crucial in the management of COPD exacerbations. Pharmacologic therapy is used to reduce symptoms, reduce the frequency and severity of exacerbations, and improve health status and exercise tolerance (GOLD, 2019). Non-pharmacological strategies improve health status and quality of life, reduce healthcare utilization, and reduce costs by preventing the frequency and severity of COPD exacerbations (Suh, Mandal, & Hart, 2013). Effective self-management programs include written action plans that enable patients with COPD to manage exacerbations and react appropriately through the prompt initiation of prednisone or antibiotics (Wood-Baker et al., 2006). Adherence to a COPD action plan can be effective in the management of COPD (Bischoff et al., 2011, Sedeno et al., 2009). The use of mHealth interventions has the potential to improve the uptake of COPD action plans.

Although there are effective and inexpensive treatments for COPD, adherence rates are amongst the lowest of all chronic diseases, leading to avoidable adverse medical outcomes, costs, and reduced quality of life. Nonadherence in COPD is documented in the uptake of all therapies, including oxygen supplementation, physical rehabilitation, and medications; it contributes to rising rates of hospitalizations, deaths, and healthcare costs (Bender, 2014). Additional strategies are needed to overcome non-adherence and barriers to optimal treatment.

### 5.1.2 mHealth for Chronic Obstructive Pulmonary Disease Management

The current literature suggests the potential for smartphone integration in the management of COPD. mHealth could play a significant role in the management of modifiable risk factors. The application of a multifactorial intervention (COPD information, dose reminders, audio-visual material, motivational aspects, and training in inhalation techniques) resulted in an improvement in therapeutic adherence in patients with COPD (Leiva-Fernandez et al., 2014). Wang et al. (2014) stated that a mobile-phone-based system can provide an efficient home endurance exercise training program with improved exercise capacity, strengthened limb muscles, and decreased systemic inflammation in patients with COPD. Another study indicated that the smartphone-based collection of COPD symptom diaries enabled patients to identify exacerbations symptoms early on in the exacerbation, providing the opportunity for early intervention (Johnston et al., 2012). Bender stated that COPD adherence may benefit from communication and advice delivered through mobile technology, along with a larger program of education, monitoring, and support (Bender, 2014).

Medical devices, such as spirometers and pulse oximeters, can obtain objective data that cannot be collected by smartphones alone. Recent advancements in technology allow for seamless integration between smartphones and medical devices. Various studies have paired medical devices, such as electronic vests, heart rate monitors, pulse oximeters, and accelerometers, with smartphone technology to assist in COPD management and detect exacerbations (Beattie et al., 2014; Barberan-Garcia et al.., 2014; Kelly et al., 2015; Kocsis et al., 2015; Nabhani-Gebara et al., 2014; Spina et al., 2015; Taylor et al., 2015; Tabak et al., 2014). However, these studies were focused on the technical effectiveness of these methods, and there was limited involvement of patients during the design of these interventions. In addition, the studies gave limited attention to patient perceptions, usability, and satisfaction.

### 5.1.3 Importance of Human-Centered Design

The International Organization for Standardization (ISO) 9241-210 standard defines human-centered design (HCD) as “an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" (ISO, 2010). The ISO uses the term HCD instead of user-centred design (UCD) to "address impacts on a number of stakeholders, not just those typically considered as users"(ISO, 2010). However, in practice, these terms are often used synonymously.

Harnessing smartphone applications (apps) as a means of delivering behavioral interventions for health is receiving increasing interest from academics and clinicians; however, research on the development and evaluation of such apps is in the relatively early stages (Dennison et al., 2013). Many of the barriers to using telehealth can be avoided with better planning and collaboration (Taylor et al., 2015). Testing mHealth interventions with patients has revealed preferences and concerns unique to the tested population (Nelson et al., 2016; Sarkar et al., 2016; Steele Gray et al., 2016). When developing an mHealth intervention, Hopkins et al. (2016) encouraged including insights from key users to potentially improve the process and the outcome of the intervention.

Triantafyllidis et al. (2015) used an iterative approach to refine a tablet computer-based home monitoring system for heart failure patients. However, there was limited uptake of the system due to usage difficulties and low levels of patient satisfaction. The authors recommended patient-centred approaches for the sustainable delivery of remote health monitoring services. Patient-centred care recognizes the complex, subjective, and changing nature of patients' health status (Upshur & Tracy, 2008); in addition, it links multiple episodes of care offered by diverse providers into continuous, integrated care trajectories unique to particular patients. Developing a COPD mHealth intervention with insights from HCPs and patients with COPD will potentially improve the process and outcome of the mHealth intervention.

### 5.1.4 Human-Centered Design in Chronic Obstructive Pulmonary Disease

Although mHealth has gained popularity in recent years, patient and HCP perspectives toward using mHealth for COPD management are relatively unexplored (Korpershoek et al., 2018). The United Kingdom has recommended that apps be "prescribed" as part of the care for long-term conditions (Department of Health, 2012). Unfortunately, few published studies address which specific features of mHealth interventions are beneficial for patients with COPD (Sobnath et al., 2017). A recent meta-analysis on the remote monitoring of patients with COPD concluded that some interventions may prove promising in changing clinical outcomes in the future, but there are still large gaps in the evidence base, including the limited number of effectiveness trials (Noah et al., 2018). Noah et al. (2018) recommend that adding a qualitative component would give researchers insight into which elements best engage and motivate patients and HCPs.

By obtaining the perspectives of nurses, physicians, pharmacists, and patients, we hope to understand their requirements for an mHealth intervention. Gaining a better understanding of how patients and HCPs interact with mHealth interventions will assist in developing evidence-based interventions that have the potential to change behavior over long periods of time (Noah et al., 2018). Lessons learned will be offered as a guide for research and technology developers working with patients with COPD and their HCPs.

## 5.2 Methods

### 5.2.1 Purpose

To explore and develop an understanding of the perceptions of patients with COPD and their HCPs regarding the appropriate mHealth features and compatible medical devices for COPD management. The study was also intended to intended to generate insights into the potential frequency of the features to ensure that patients and HCPs remain engaged with and responsive to the mHealth intervention.

### 5.2.2 Study Design

We used a descriptive qualitative research design that was grounded in pragmatism (Merriam & Tisdell, 2015; Patton, 2015). Using a qualitative methodology allowed us to achieve an in-depth, contextualized picture of what a diverse sample of patients with COPD and their HCPs, in this case, nurses, pharmacists, and physicians, think and feel about the possibility of using mHealth in COPD management. This has pragmatic value, as mHealth is an emerging option for delivering health care.

### 5.2.3 Recruitment and Study Setting

HCPs involved in the treatment of patients with COPD were eligible to participate. The primary investigator (PI) contacted the Newfoundland and Labrador Medical Association, the Association of Registered Nurses of Newfoundland and Labrador, and the Pharmacists' Association of Newfoundland and Labrador. These organizations were asked to forward a recruitment email to their mailing lists or post it on their websites. Interested HCPs contacted the PI via email or telephone, who then scheduled appointments to complete the consent forms and conduct the interviews.

Patients were recruited during routine visits to their respirologists at outpatient respirology clinics in the Eastern Health Regional Health Authority of the province of Newfoundland and Labrador, Canada. Participants were eligible for the study if they met the following inclusion criteria:

1. a COPD diagnosis (self-report),
2. aged ≥30 years at study enrollment,

3. able to answer questionnaires in English, and
4. able to provide informed consent.

Based on the demographic information collected from patients, a purposeful sampling strategy was used to identify key informants that could provide rich and diverse interview data. We used purposeful typical case sampling to gather information that would reflect typical cases of mHealth use (Patton, 2015; Creswell, 2016). We also used a criterion-based selection (Patton, 2015) so that we could categorize participant characteristics such as age, familiarity with mHealth, healthcare profession, and years of experience. In addition, as the interviews progressed, some participants were recruited by snowball or chain sampling, where participants suggested other possible HCPs (Patton, 2015, Emerson, 2015). Snowball or chain sampling was used to ask a few information-rich participants for additional contacts to provide confirming or different perspectives, allowing for richer data (Patton, 2015).

We first contacted nurses, and after interviewing eight nurses, we reached saturation, as we were not gathering new information. However, we continued interviewing until 10 nurses were interviewed. This was to strengthen the validity of inferences (Maxwell, 2013). We used the same sampling strategy for the remaining professions and patients, with similar saturation points, as we continued to interview ten participants for each profession and for patients. Our final sample size was comparable with similar qualitative studies (Damhus et al., 2018; Korpershoek et al., 2018; MacDonald et al., 2018).

Participants were recruited from April 2018 to August 2018. Our sample consisted of 10 patients and 30 HCPs: 10 nurses, 10 pharmacists, and 10 physicians. The study took place in St. John’s, Canada. We conducted some interviews at Memorial University and others at the participants' offices or homes. After completing the interviews, patients were offered a $30 gift card.

### 5.2.4 Ethical Considerations

Ethical approval for this study was obtained from the Newfoundland and Labrador Health Research Ethics Authority (HREB -2017-194). Before agreeing to participate, all subjects were informed about the nature of the research project, the possible risks and benefits, and their rights as research subjects. All participants completed a written consent form. They were also given a copy of the consent form.

### 5.2.5 Data Collection

We conducted individual semistructured interviews to gain an understanding of the everyday lived experiences of HCPs and patients in relation to using mHealth (Brinkman & Kvale, 2015; Rubin & Rubin, 2012). Using semistructured interviews allowed the interviewer to begin with a broad question to direct the focus of the interview and then to provide an opportunity for the HCPs and patients to bring forth their thoughts and feelings about phenomena they thought were important (Brinkman & Kvale, 2015; Rubin & Rubin, 2012). The interview prompts are available in Appendix 1 (for HCPs) and Appendix 3 (for patients). To facilitate discussions, the interviews were conversational in nature, and items were not asked verbatim or in the order presented. As the study progressed, emerging issues were explored with subsequent participants to refine the themes. The prompts were informed by findings from the literature and input from the authors, who have diverse backgrounds including mHealth, pharmacy, nursing, medicine, respirology, family medicine, education, and qualitative research.

The interviews were recorded to enable transparent and accurate transcription. Interview lengths ranged from 20 to 60 min. Topics included the following: demographics, mHealth usage, perceptions toward challenges of mHealth adoption, factors facilitating mHealth adoption, and preferences regarding features of the mHealth intervention for COPD management. Topics also included discussions about smartphone-compatible medical devices (accelerometers, portable spirometers, and pulse oximeters). Owing to a large amount of data, preferences regarding the barriers and facilitators of mHealth adoption for COPD management were presented in different articles (Alwashmi et al. 2019a; Alwashmi et al., 2019b). HCP data consisted of more than 13 hours of interview time with approximately 300 pages of transcription. Patient data consisted of about four hours of interview time with approximately 100 pages of transcription.

### 5.2.6 Data Analysis

The interviews were transcribed verbatim and compared against the digital recordings to ensure the accuracy of the content. Identifying information (names) were removed to protect anonymity. We used NVivo (version 12; QSR International) to organize the data and examine the words, including frequency counts, as in classical content analysis (Leech & Onwuegbuzie, 2008). All data were analyzed, but we only coded data that were relevant for answering the research questions, as recommended by Saldana, 2015; Wolcott, 2009; and Yin, 2011. An audit trail was created to keep track of all analytic decisions (Guest et al., 2012).

After using NVivo, we used first cycle coding with nurses' data that were both structural and holistic (Saldaña, 2016), meaning that we used the interview prompts and the literature to guide some of the coding. One researcher analyzed the transcripts and developed a set of themes and subthemes and then obtained input from a second researcher. In the second cycle of coding, the two researchers independently coded the nurses' data using pattern coding to develop themes (Saldaña, 2016). They then discussed commonalities and differences in their coding and theme development until a consensus was reached. The analysis of the nurses' data was mainly inductive and iterative throughout, as we went back and forth among the data, the coding, and the themes (Miles et al., 2014).

After the nursing analysis was finished, we completed the same two cycles of analysis for the pharmacist, physician, and patient data. These analyses included inductive and deductive analysis. However, the analysis was more deductive in nature, as themes had already been developed from the nursing data. Furthermore, some new themes emerged when analyzing data from patients and other HCPs. The iterative process continued as these analyses were conducted to find commonalities, differences, and new patterns in thinking in relation to the nurses' data. Once these four sets of analysis were complete, the two researchers discussed common and different trends among the three HCP groups and patient group to develop final themes that encompassed all the HCPs and patients.

## 5.3 Results

The results are organized in three sections. The first section describes the demographics of the sample. Then, the features of the patient interface will be highlighted in the second section. Lastly, the third section describes the features of the healthcare professionals' interface.

### 5.3.1 Demographics

The sample included HCPs who worked with patients with COPD in various settings, including respirology clinics, cancer clinics, critical care, long-term care, and community health. Some HCPs founded a medical technology company or had a software programming background. About half the HCPs had experience with an mHealth intervention to manage COPD. Participant demographics are outlined in Table 5.1.

**Table 5.1:** Participant demographics.

| | Sample size | Age mean (SD) | Years of experience mean (SD) |
|---|---|---|---|
| **Nurses** | 5 | 47.3 (6) | 19.6 (9) |
| **mHealth* Nurses** | 5 | 40.6 (10) | 15.8 (10) |
| **Physicians** | 5 | 37 (9) | 8.4 (8.7) |
| **mHealth* Physicians** | 5 | 41.2 (12) | 14.4 (11) |
| **Pharmacists** | 7 | 35.7 (11) | 11.4 (10) |
| **mHealth* Pharmacists** | 3 | 27.5 (4) | 3.6 (2) |

mHealth: experience in using an mHealth intervention.
SD: Standard Deviation

Ten patients with COPD participated in face-to-face interviews. The mean age was 67.6 (±7.58) years, and the range was from 51–80 years. There were four females and six males. Based on self-report, the mean number of years living with COPD was 8.4 (±4.45) years, and the range was from 3–15 years.

### 5.3.2 Patient Interface

The mHealth interface is defined as the way in which information is made available to users on the screen (Combley, 2011). We developed themes under two categories: patient interface and HCP interface. Table 5.2 summarizes the main features recommended for the patient interface. We have also included details and examples to illustrate the HCPs' and patients' thoughts and beliefs.

The patient interface allows patients to access features of the mHealth intervention. The authors recommend using a smartphone to access these features. In addition, a tablet or a laptop can also be used. This section explains how patients and HCPs think these features would be beneficial in the management of COPD. The following themes give examples of how patients and HCPs can work as a team in a complementary fashion to improve patient health.

**Table 5.2:** Themes with specific examples regarding the features of the patient's interface.

| Theme | Specific examples for each theme |
|---|---|
| The educational component is valuable. | A source of reliable information is important.<br><br>Topics include information about the disease, medication, inhaler techniques, and breathing exercises.<br><br>The educational content can be delivered via messages, videos, or walkthroughs. |
| It is important to collect baseline information. | It is necessary to understand the patient and evaluate the COPD management progress.<br><br>Information should include demographics, health data, psychosocial data, primary care physician, and emergency contact. |
| It is important to collect subjective health data. | It is necessary to understand the level of COPD management and guide pharmacological therapy.<br><br>Information should include shortness of breath, cough, and sputum.<br><br>Data about medication adherence, exacerbations, and hospitalizations are important. |
| It is beneficial to collect objective health data. | Objective data for monitoring COPD are helpful.<br><br>It could reduce the reliance on healthcare resources.<br><br>Medical devices could potentially include a portable spirometer, pulse oximeter and a medication adherence monitor.<br><br>Additional devices can be added, especially if the patient has a comorbidity. |

| | |
|---|---|
| Providing a COPD Action Plan is recommended. | It has the potential to empower patients to be a part of their management plan and reduce hospitalizations.<br><br>It could use the subjective and objective data to personalize COPD management. |
| Allowing patients to track their COPD management progress would be helpful. | The ability to track the progress of the subjective and objective data. |
| Providing access to family members or caregivers would be beneficial. | Family members or caregivers can assist in the delivery of the mHealth intervention. |
| Consider tailoring the features based on the patient’s unique needs. | Differences in COPD severity level and presence of a comorbidity can affect the features required by patients.<br><br>Personalizing the features include changing the frequency of objective and subjective data collection. |
| Reminding patients to manage their COPD is a benefit. | Reminders include taking medications, refilling prescriptions, and attending hospital appointments. |
| Rewarding patients for managing their COPD is a possibility. | Using positive reinforcement messages or reward programs can be motivational. |
| There were a few features mentioned by a minority of HCPs and patients. | Features include:<br>Using artificial intelligence.<br>Consider visually impaired patients.<br>Ability to share the records with any HCP.<br>Ability to access medical records.<br>Including a smoking cessation program. |

##### *5.3.2.1 The educational component is valuable*

Pharmacists, nurses, and physicians agreed that mHealth can have a role in educating patients with COPD. One pharmacist remarked, "... COPD is something they'll have for life. So especially when they're getting diagnosed that this is introduced as a tool for education, for making sure that it doesn't get worse". Similarly, a physician felt confident that patients would "learn more about their own disease and if they know more about their disease, then, like, generally speaking, they're more invested in their care". A pharmacist raised a point that getting educational information through an app is better than "having to Google the information and coming across misinformation".

HCPs had strong thoughts regarding the educational content of the mHealth intervention. The majority of HCPs agreed that it should include information about the administration technique of inhaled medications. This physician statement represents the thoughts of several HCPs: "Because if I'm giving them the best drugs but they're only getting 25% of the drug because they're not using the device properly then that may be some of the reason they're having a poor quality of life". More generally, a pharmacist put forward the importance of patients being able "to better understand their condition and the importance of their medications... And understanding the disease process and how the importance of each medication in preventing it or treating it". More specifically, a pharmacist recommended including breathing exercises. And, to summarize the content, one pharmacist remarked that the educational content should include "the patient information sheet that a patient would get upon counselling".

To deliver educational content, HCPs talked about several methods. Some HCPs recommended daily sessions, while others recommended monthly sessions. These educational sessions can be delivered via messages, videos, or walkthroughs, as in this pharmacist's comment: “So if there’s some sort of demonstrative capabilities where you could just click on it and have someone walk you through the technique. I mean the pharmacist is doing that but then a month later if they say oh I forgot it, you know, how did they tell me to do it again the reminders help”. Additionally, some HCPs recommended making a library of the content available so patients could access it at any time.

One nurse explained how to provide educational sessions:

> *Each day when they do their health session, they get one to two what we call education slides within their health session and it's just three to four sentences about COPD. So, it could be just some signs and symptoms, it could be a tip of the day to help keep them healthier at home, that sort of thing. Also, on the iPad there's encrypted in there some videos specifically for... there's more for COPD. It's a two- to three-minute video on COPD to help them understand their disease process a bit better. There's also videos on shortness of breath and there's a good video on showing them how to properly take deep breaths in and how... in order to help them decrease their shortness of breath, videos on how to use their inhalers properly along with even what we call very important too, just the signs and symptoms and the importance of keeping your blood pressure under control, so it will tell them symptoms of high blood pressure and what can cause low blood pressure, heart rate high and low along with oxygen... what a low oxygen reading could mean for them and the seriousness of breath. what can happen with a low oxygen reading.*

In addition, the mHealth intervention could be used to deliver “new research or new, you know, something has come about that they should know”.

Patients also thought that the mHealth intervention could be used to provide educational materials. All patients who were enrolled in an mHealth intervention for COPD management mentioned that they read some of the content provided. One patient remarked that he particularly enjoyed the educational tips that were presented as a notification: “They had certain hints on how, it might be on congestive heart failure or it might be on something else, but they’re all helpful. You learn things from them”. However, one patient had contradictory views about using mHealth to provide educational materials, as in “I have got so much information home now on COPD that I have not looked at”.

#### *5.3.2.2 It is important to collect baseline information*

Collecting baseline information is vital to understanding the patient and evaluating the COPD management progress. This nurse’s statement represents a commonly expressed thought: “I think the most important piece of that is to halt before you just go out and put a device in a patient’s home is to understand what their normal is”.

When enrolling a new participant in the mHealth intervention, nurses supported the idea of collecting baseline data including: name, date of birth, address, who they live with, support systems, gender, and age. The nurse highlighted the importance of collecting “ baseline information about their overall health condition. Definitely, we would want to know if they’re a smoker or not, where they’re from, do they have any medical histories, family history”. HCPs also recommend identifying the primary care physician (PCP): “once a month we will send out their PCP a monthly report of the biometric readings”. Emergency contact information is also important: “if we still did not reach the patient and we felt that the result was potentially life-threatening, we need three contact people who we can call. And if we cannot reach either of them then we call the police to go in and do a well check just to be sure”.

Nurses stated that it is important to collect information on the psychosocial aspects of the patient:

> *What they're dealing with at home, where they live, what their environment is. In terms of whether or not they can afford their medication. Whether or not they eat healthy, whether or not they get out of their home, you know. Do they live in an area where they're safe to get out and go for a walk or, you know, do they live in an area where there's no sidewalks or something that might inhibit them from getting out? Are they in a basement apartment? Do they have a bunch of grandchildren? Do they have no-one?" These aspects also include if "people smoking around them? Do they smoke themselves? Is that what you are getting at? Do they live in a basement apartment or top floor of a house? Those sort of things, physical environment?.*

#### *5.3.2.3 It is important to collect subjective data*

Collecting subjective data from patients via surveys was recommended by the majority of HCPs. The aim is to have a record of various symptoms to understand the level of COPD management. These symptoms include shortness of breath, cough, and sputum. Depending on the answers to these questions about symptoms, one nurse advocated to include "branching questions to see what colour the sputum is and things like that". HCPs also expressed interest in collecting data regarding medication adherence and medication side effects; for example, a pharmacist stated that "Adherence is the most important data point for everything with COPD". Collecting the number of exacerbations and hospitalizations was also mentioned by HCPs, as in the physician's statement, "I know there's the CAT questionnaire on COPD. You can see when there are more dyspnoeic offs. And they can also log when they have exacerbations, so when they come to the hospital". This was reiterated by another physician: "Number of hospitalizations related to their COPD, number of times that they're using prednisone per year, number of times that they're having flu-like symptoms or any pneumonia or chest infections". One nurse noted the importance of taking physical activity into consideration when assessing patients with COPD, as in "Things like activities of daily living. So, sometimes my patients would describe, relatively well, COPD management but it was because of not moving at all". A minority of HCPs mentioned collecting data regarding smoking status, oxygen usage, and depression scores.

When asked about the frequency of the survey, HCPs had conflicting opinions. Some HCPs thought a daily questionnaire would be feasible. A nurse with experience in mHealth interventions stated that a daily questionnaire did not affect the compliance rate, as in, "whole session, from biometrics to symptom question and answers will take five to ten minutes... I would say it would be probably about 90% to 92% compliance rate for patients who will complete their sessions". This was also agreed upon by the patients who were part of the mHealth intervention. In addition, patients who were not enrolled in the mHealth intervention were open to completing a daily questionnaire, as in "If I get a notification that I need to answer some questions, it's going to take me five or ten minutes, I've got no problem with that". Alternatively, the majority of HCPs surmised that daily surveys are not feasible, as in "I think that would make them a little turned off from the app if they had to fill out a survey every day". Two patients were not supportive of completing a survey on a daily basis: "I am pretty sure I would get pissed off with it and say...I am not doing it." Some HCPs suggested that the frequency of the questionnaire should depend on the COPD severity, as in: "I don't know the exact timeframe, but for someone who is stable and well, I think that it could be very, you know, patients could lose their sense of self-control because they're just having to do this daily thing and it’s a bit tedious, but I think that for the acute patients, definitely daily, and patients should be able to recognize when they need to do that”. This was reiterated by a nurse: “divide it into different sections depending on how complicated their health condition is”.

One pharmacist felt confident that the mHealth intervention could play a role in guiding pharmacological therapy: “If there’s no improvement, then what’s the point of keeping them on the drug? ...The patient can provide that information to the doctor... They can even just view it and then send a prescription into the pharmacy and the patient can go get it”.

#### *5.3.2.4 It is beneficial to collect objective health data*

It is common among mHealth interventions to use Bluetooth technology for pairing medical devices with smartphones. This is a user-friendly method that allows the transfer of results from the medical device to the smartphone and eventually to the healthcare provider platform:

> *Everything is done through Bluetooth and so they're provided with a blood pressure cuff and pulse oximeter to check their oxygen readings and they're also given weight scales and, again, all this is Bluetooth-compatible and patients have to have cellular connection or Wi-Fi in order to be in the programme, because that's how it's all transmitted into the individual nurse's monitors.*

These devices allow patients and HCPs to obtain objective data for monitoring COPD. This was observed by a nurse who uses an mHealth intervention: “it validates that the condition is certainly stabilised and not worsening. And I think, if nothing else, it is peace of mind for the patients and so on”. Additionally, pairing medical devices could reduce the reliance on healthcare resources, as stated by a pharmacist: “I think that would be particularly valuable if you’re getting meaningful medical data that doesn’t necessarily require healthcare resource to be tied up. You don't have to send the client to a clinic to have these sorts of examinations or tests completed if they can do at home at their own convenience. I think that's a win-win for everyone". HCPs voiced their opinions regarding the use of a portable spirometer, pulse oximeter and a medication adherence monitor in COPD management.

When asked about the use of a pulse spirometer to monitor COPD, most HCPs thought that it is important to measure oxygen saturation. A pharmacist, echoing other HCPs, indicated that it would "definitely be a good idea because getting that like reinforcement of having that number come up, they might be like, okay, I'm not doing so well right Now". In terms of the frequency of measuring oxygen saturation, many physicians mentioned that measuring it daily would be a general role, but one physician recommended tailoring it to the severity of the diseases: "I guess, it depends as well based on the severity of their disease but, I guess, on a daily basis again for somebody who's quite short of breath and has low O2 stats, then less often for people who are better".

Four patients who were enrolled in an mHealth intervention to manage their COPD used a portable spirometer on a daily basis. Support for this practiced was voiced by others, as in this patient statement: "everyone has to have an oximeter. And I'm very surprised that an awful lot of COPD patients don't". It was also mentioned by another patient: "What I found so good with that was testing your oxygen, how much oxygen you got, you know, because that was really helpful. Because if you wait until you have a hard time breathing, that's not good". These patients were supportive of testing their blood oxygen levels daily.

When asked about the use of a spirometer to monitor COPD, HCPs had contradictory views about its use for monitoring purposes. A few HCPs thought that it is important to measure the lung volume. The following physician statement supports the inclusion of a portable spirometer as part of the mHealth intervention: “After acute exacerbation, I think that you should, the recommendation is that you should get repeat PFTs, like, 12 to 16 weeks post-discharge. And I don’t think that that’s being done currently...if patients had spirometers at home, that this could alleviate some of that repeat PFTs for people so that they can monitor their severity of their COPD”. This was also supported by a patient: “my doctor generally orders it, but it’s not more than once a year and sometimes I haven't had it for a year and a half, maybe two years. I told you I’ve been diagnosed about six years and I’ve probably had four”.

Alternatively, other HCPs did not recommend adding a portable spirometer to the mHealth intervention. One reason given was that patients may have trouble interpreting the results. A pharmacist noted, “I don’t know if everyone is going to be able to interpret the results properly. But that’s not to say that they could just bring them to their physician”. A nurse stated that “if the spirometry is going to go back to a respirologist then definitely. But if it’s going back to a staff nurse then perhaps the nurse would rather see other biometrics”. Physicians suggested that patients will not be able to perform spirometry independently, as observed by a respirologist: “There’s no coaching. And that’s prone to error, right off the bat, right, so sure, it might be helpful in terms of long-term trends, but I’m not sure it’s that useful”. Another physician questioned the ability of patients with COPD to perform spirometry:

> *I feel like that would be more of a technique issue, so not all the patients have the best technique and then that’s one thing, Also, there’s a timing issue as well with the inhalers, so sometimes patients take inhalers right before they do it and can throw off the data a little bit and then sometimes patients don’t take it. So, I think that’s, it’ll be more challenging to do that, personally”. Some HCPs thought that patients will not be*

*interested in using the spirometer, and a pharmacist mentioned: "The average patient is not going to see the value of it and they're not going to do it.*

In terms of the frequency of a spirometry test, there were varying opinions among HCPs. One pharmacist recommended performing it daily: "technically they should be doing it daily. I mean, when a patient had asthma we normally recommend doing it daily because with asthma there's also actions that need to be taken with using spirometry". This was also mentioned by a physician who was hesitant about the frequency of testing: "Yes...Once a day... Maybe, I don't know... Somebody who is very mild and the spirometry results have been really good, maybe once a week. People who are more severe would probably do it more often on a daily basis". On the other hand, a respirologist said, "I'm not sure if it's worth the money to do something like that on a daily basis". Other HCPs recommended using a spirometer every few weeks or months: "if it's only a small procedure, it's not invasive, there is no reason they can't do it every few months, because if I remember right, the FEV tends to not change massively in a short period". One physician expressed interest in tailoring the frequency to the individual based on defined criteria: "If you had strict clinical criteria as to when the FEV1 would be done, as opposed to okay do it once a month or whatever it is, you know, because it's a clinical decision, it's not a time based decision".

A physician talked about conducting a study to determine the ideal frequency for measuring lung volumes: "I think the only way to know that is if you had the device and you actually studied that...So to me it would be to correlate that with the measurements and then changing their breathlessness or their sputum or other things to try to figure out is there clinical things that we could ask that would give us that information without having the technology. But as technology gets cheaper and more available then yes, for sure, I mean it's no different than if you look at the insulin pumps and having the instantaneous monitoring now which we never had before and being able to give insulin in a much more physiological basis. So I think it could be helpful". A few patients were interested in trying a portable spirometer but were not sure of how often they would have to perform the test, as in "Yes, probably once a week I'd get used to the hard blowing". A patient shared her opinion: " I could learn to use it. I don't think I need it as long as I'm doing what I'm doing now".

Many HCPs thought that the use of a medication adherence monitor could be effective for COPD management, as one pharmacist said, "That will be really good for Ventolin because then you can actually see how much they're actually using". This was reiterated by a nurse: "Oh yes, I think that would be very useful, because sometimes, and I hate to say it, you can't really believe the patients". One physician suggested using a camera to promote medication adherence: "Right now I mean most times I prescribe inhalers I don't actually watch patients take the inhaler. But if you're able to say well take a little video of yourself and I'll look at the video of you using the puffer this evening. That ability to actually measure compliance based on the ability that if you have remote monitoring you could observe the patient using their device". Furthermore, a pharmacist suggested adding a device to an inhaler to assess the inhalation technique: "You can go to YouTube and you can see how to use an inhaler and they're very, very good and I don't think that the app would necessarily be able to do that unless it was somehow linked to the device and somehow knew whether you were doing it incorrectly". Many patients were also interested in using a medication adherence device, as in "That absolutely amazes me. You mentioned, like, this counter and that for your puffer. That's a very good idea. And also, this pulmonary function test. You have to know, especially in this day and age, the reason, I guess, you're coming out with these programs, is that there's only so many doctors to go around".

Some HCPs recommended using other devices, especially if the patient has a comorbidity. These devices could be used to measure weight, respiratory rate, blood pressure, blood glucose levels. A nurse with mHealth experience shared, "If you were doing the oxygen, vital signs, the whole blood pressure and pulse and respiratory rate wouldn't go astray either". One pharmacist with experience in mHealth suggested that pharmacies can offer medical devices to be used by patients that can send data from the medical device to the patient's phone.

Patients who were enrolled in an mHealth intervention to manage their COPD used a blood pressure monitor and a scale. Additionally, patients with cardiovascular comorbidity used a blood pressure monitor: "When I had a problem with blood pressure about four or five years ago I used to have to use it quite a lot because used to have to keep a record for my family doctor. So since I got it under control now, some days when I feel a bit flushed in my face well I'll check it and make sure that it's not gone up anymore". Two patients used a glucometer to manage their diabetes comorbidity. An accelerometer, Fitbit, was used by one patient, as in:

> *I kind of slow down a bit and I started feeling more with my joint pain. And I said what I need, I think it's better for me to track what I do every day going to make me feel better. So they recommended the watch so I just start from there... Normally every day...I check my sleep and check how I stressed and how much I eat, how much calories I burn in a day, how much I walk and my heart rate. It's amazing.*

#### *5.3.2.5 Providing a COPD Action Plan is recommended*

The majority of the HCPs supported the idea of including an action plan as part of the mHealth intervention. One nurse was already using the COPD Action Plan in her practice, as in:

*we do promote something called COPD action plan... the whole premise of it is so they could have antibiotics and steroids on hand at their pharmacy in case they start to have a flare up. We educate them on when they should use this and the whole premise is to treat early so as they don't get to the point that they do end up having to go to an emergency room or be admitted. So based on that assessment the outcomes of individual cases that we handle is either to recommend that the patient take an extra inhaler, to use a nebuliser treatment, to increase the frequency. We may reach out to their physicians if we feel a change in their care plan is required. To get new orders for new treatment orders or, if it sounds to be a very acute situation that is not relieved with any home care measures, then we either refer to their physician, emergency department or, in some cases if they are in acute respiratory distress, we actually arrange an ambulance to come on site and visit.*

Several HCPs surmised that including an action plan had the potential to empower patients and reduce hospitalizations. One physician reinforced this notion and thought the action plan "would give patients the power to then be a part of their management plan, which is better when patients are empowered because they feel in control of their health. And then also would give them, you know, a couple of strategies before they need to go to the emergency department and, you know, people with COPD, it is hard for them to go out and walk to their car or take transportation to the emergency department. It can take an awful lot of effort, so it saves a patient as well as the healthcare system some resources as well". A pharmacist stated that patients would not lose the action plan, which is common among paper-based action plans: "if they could customize like a COPD action plan or something like that in the app where they're not going to lose it would also be beneficial to patients."

Most importantly, HCPs agreed that the action plan could use subjective and objective data to personalize COPD management. A physician provided the following example:

> *there could be an algorithm within the program to say, are you more short of breath, yes, are you having increased sputum production, yes, what is your oxygen saturation level, 87, what is your temperature, 37.4, and based on this information, then the application could say, you know, increase your short-acting bronchodilator, increase your short-acting agent just based on that.*

Three patients mentioned that they have a COPD action plan. In terms of using an mHealth intervention to deliver an action plan, one patient remarked, "I would be open to using my phone to help manage my COPD based on what that entails. If it's a few questions in terms of information gathering to help sort of develop a micro-specific COPD treatment regimen, I could absolutely see the benefit in that. If it would be for generic information gathering, I probably wouldn't be so open to that".

#### *5.3.2.6 Allowing patients to track their COPD management progress would be helpful*

Some HCPs suggested providing patients with the ability to track their COPD management progress. A nurse thought that patients should be able to "see their signs and symptoms. Is this normal? Is this abnormal? Can I manage this myself with what I have got at home or should I go to the emergency department?" Some pharmacists suggested summarizing the signs and symptoms to share with HCPs, as in "I'd bring up my app and it would give me a simple one-page snapshot of how I'm doing. And then, from there, I could click on different areas and, you know, get some tips or whatever. It needs to be very simple…because if they went to their physician or to us and they hold the phone and say, here, let's have a look".

Many patients were interested in tracking their progress, as in "It's a critical factor. It's my health. But beyond all of this, I would really like to understand why I have COPD...I would definitely want to track my progress or regress accordingly and if the app would allow me to do that." One patient kept a web-based record of his vital signs and medication adherence: "I can go back five and a half years and tell you, on the third of May, that I took my pills at eight seventeen AM in the morning".

#### *5.3.2.7 Providing access to family members or caregivers would be beneficial*

Many HCPs mentioned that granting caregivers, family members or homecare workers access to assist in the mHealth intervention would be beneficial. A physician stated, "I guess they do often have children, grandchildren, homecare providers, people who can help or have it on their own phone when they're with them". When sharing information with family members, a physician was concerned about the importance of ensuring privacy and confidentiality: "the only issue that you'll come across there is the, you know, release of information because patients, you know, if they're competent they don't want their family members to see their information and that could be an issue". The majority of patients mentioned that a family member assisted them in the management of their COPD, as in "I've got a little organizer I put my pills in there for the week…And if I don't, my wife gives me a smack in the back of the head".

#### *5.3.2.8 Consider tailoring the features based on the patient's unique needs*

A recurring theme among HCPs and patients was tailoring the mHealth intervention to each patient. Differences in COPD severity level and the presence of a comorbidity can affect the features required by patients. Personalizing the features includes changing the frequency of objective and subjective data collection. For example, a physician commented, "The question is do you want it to be individualized to the patient...You don't want to overwhelm patients with collecting all this information, right, it needs to be something that is beneficial to them and not just something else that they're having to do". A nurse describing her monitoring approach with patients enrolled in an mHealth intervention to manage COPD: "It would be patient-specific for sure. Somebody who is well and didn't do a session for a couple of days, maybe we'd let it slide. But somebody who you know had been unwell for a few days and if they didn't do their health session, say by mid-morning, maybe you'd might call them and say, are you okay? What's going on?"

Although this mHealth intervention is focused on COPD, many HCPs illustrated the importance of considering COPD comorbidities. A nurse gave this example: "Often it was either coronary artery disease, diabetes, hypertension. That's the group that you tend to see most often". This thought was reinforced by others, as in this physician statement: "nobody has one condition, right, particularly if you're looking in your, sort of, 65 plus patients, right, they're all going to have probably, in Newfoundland anyway, a minimum of three comorbidities". Furthermore, some nurses supported the idea of adding a glucometer or a blood pressure monitor, based on the comorbidity, to the mHealth intervention.

The majority of patients who participated in the interview had a comorbidity. Among these comorbidities were diabetes, congestive heart failure, cancer, and arthritis. A patient stated, "I am a walking disease! I have got high blood pressure, I got high cholesterol, I have got a problem with my thyroid, I have got a problem with walking…I have got a problem with my eyesight and hearing".

#### *5.3.2.9 Reminding patients to manage their COPD is a benefit*

Many HCPs rationalized that the mHealth intervention should remind patients to manage their COPD. Giving patients reminders to take their medication was most frequently suggested by HCPs, especially pharmacists, as in, “Adherence (with medications) would be a big thing because patients are not great with that so if the app had reminders, and reminders of dealing with side effects; if they need to rinse their mouth out after, or little things like that”. One nurse reinforced this notion and thought the mHealth intervention could remind patients to manage their COPD based on objective data collected by medical devices:

> *let’s say, your respiratory rate went above 28 or 30 or whatever, whatever parameters that the nurse could set. Then the patient would get some, kind of, notification to say, what am I doing or it’s time for me to sit or maybe some notification, have you taken your medications today. Little reminders maybe or something that could pick up on their heart rate. And I think that might be the way of the future.*

Lastly, one nurse talked about reminding patients about refilling prescriptions and their hospital appointments “so they know what is coming up that they are not going to miss appointments. They are going to have their appropriate test done, they are not going to miss appointments because it is already in the app. Here we have a high percentage. On average if you have got a clinic of 14 patients, sometimes two don’t come because they didn’t get notifications”.

#### *5.3.2.10 Rewarding patients for managing their COPD is a possibility*

A few HCPs suggested using a reward system to motivate patients to use mHealth for COPD management. One pharmacist with experience in mHealth commented, “rewarding people is the best way you can get people to appreciate an app...it might be rewarding just with positive reinforcement, which is if they do three weeks in a row of 90 percent adherence to therapy, they get a notification or something to say, great job, you’re doing really well”. Some HCPs elaborated on using rewards to encourage patients to stop smoking or “to reinforce adherence, proper administration of the medication and proper timing”. A pharmacist and a physician recommended a motivational app to their patients "I've recommended a couple of patients try this Carrot app...for patients that are trying to lose weight, they could use and record their weights and probably to set goals".

##### *5.3.2.11 There were a few features mentioned by a minority of HCPs and patients*

Additional features were mentioned by a small number of HCPs. For example, one physician pointed out the use of artificial intelligence in the mHealth intervention, as in "they always talk about how the AI's going to be, sort of, embedded in our EHRs, and I get that and I know that that's coming". A pharmacist expressed interest in including a feature to include visually impaired patients: "It would help if it could talk to you because then it could be used for people with visual impairment". One nurse with experience in conducting mHealth interventions recommended that program administrators should conduct monthly satisfaction questionnaires with patients and healthcare providers. The questions could include "Were you satisfied? Did you follow the nurse's advice? What was the outcome? Are you experiencing any difficulties with the device?"

One nurse suggested adding information about "interactions between their medications if they are going to get new medications, put it in and it would give them a high alert or a low alert". Lastly, a physician had contradictory views about allowing the patient to access their laboratory test results, such as blood work: "if patients had access to their blood-work and to their reports, that could be set up so that you could only access your own personal stuff and that would then, maybe, be helpful, because the biggest problem is if something gets missed and if you have access to your own reports, that can help. The only negative of that is it causes anxiety because for a patient when you see something or you're reading something and you really don't know what it means".

A pharmacist and a physician expressed interest in using the mHealth intervention to aid in smoking cessation. A pharmacist describing an mHealth intervention that she recommends to patients noted, "you put in your quitting day in it and it gave you some sorts of kind of rewards and sent you congratulations messages and that sort of thing. And you could go on and see how many Dollars you've saved by quitting smoking, different things that happen every day as you quit what happens in terms of improving your lung function and that sort of thing. Also when a patient was having a craving they could actually go onto the app and play a game that would distract them for a couple of minutes to allow the craving to pass".

Patients did not recommend many features. The following patient statement represents thoughts from several other patients: "Really, you know far more than I do in terms of what will make for a very functional set of parameters". Some features suggested by patients were medication and sleep tracking: "Yes I think if I sort of keep track of what I think will be my approximate amount of sleep the night before, stress levels possibly. That could be all important".

### 5.3.3 Healthcare provider interface

Nurses, pharmacists, and physicians would require an interface to engage with the patients. One pharmacist talked about including other HCPs, "potentially other workers in the healthcare system, social workers, you know, maybe physio. So I think everybody in the healthcare system has a role to play in it and hopefully by combining that you get a more robust outcome". Table 5.3 summarizes the main features recommended to assist the HCP.

**Table 5.3:** Themes with specific examples regarding the features of the healthcare professionals' interface.

| Theme | Specific examples for each theme |
|---|---|
| Allowing HCPs to track their patients' management progress is important. | Tracking data, including vital signs and medication adherence, is important.<br><br>Tips on how to present and access the data would be beneficial. |
| Allowing HCPs to communicate with patients and other HCPs is beneficial. | Automating a monthly report to be shared with the primary care physician would be helpful.<br><br>Ability to manage requisitions and prescriptions would be beneficial.<br><br>Opt-in to receive information regarding specified criteria or variables could be helpful. |
| The educational component is valuable. | Including current best practices and guidelines on COPD management would be useful. |
| Remunerating HCPs is a possibility. | Delivering existing COPD adherence programs that are funded by a third party would be beneficial. |

#### *5.3.3.1 Allowing HCPs to track their patients' management progress is important*

All HCPs stressed on the importance of using HCP interface to access the data collected from patients. Many HCPs discussed the importance of viewing information related to the patients' signs and symptoms. A nurse suggested having the ability to view "their vitals, their levels of activity... oxygen saturation, oxygen usage, those types of things". Other important information that can be accessed from the HCP interface is data regarding medication adherence, as in the following pharmacist comment: "as a pharmacist, would be useful to explore to see if there's anything we can do to help overcome barriers or facilitate adherence". Some pharmacists felt confident that viewing data longitudinally would be valuable in choosing the right therapy, as in "So I see the most value in the initiation or changing of therapy...If you can actually see over a period of time, well, is that helping or not, then you can make a decision whether it's actually making a difference". Furthermore, a physician gave this example: "What I would appreciate as a physician is seeing longitudinal progress of my patient... because I want to know, did we just have that one acute episode, was there, kind of, many acute episodes that never actually came into me".

The following physician statement represents thoughts from several other HCPs: "I want all the data if I'm a research scientist because I'm trying to prove something but as a clinician, I want the data that's going to impact my patient care and quality of care". This was supported by a pharmacist, as in "so it's having the relevant data to make the right clinical decision rather than having all the data". To deliver the right data to HCPs, they suggested summarizing the information, as in this physician's comment:

> *there should be a way in the app to maybe synthesize it down a little bit or else you'll just have a lot of data points without much direction... so maybe highlight areas of concern and maybe highlight, like, the averages of, say, blood pressure or saturation levels, stuff like that.*

A few HCPs rationalized the use of trends and outliers, as in "I think in the short amount of time I think pharmacists and physicians learn to look for specific things right...you're looking for some outliers and you're looking for trends and patterns and things like that". Some HCPs suggested using graphs to present these trends. And, a nurse commented on her patients who were enrolled in an mHealth intervention to manage COPD: "we would set parameters, say for the oxygen saturation, if they were less than 88 it would be red on the screen. So, of course, those would be the people that you would triage and call sooner than the others to check in on them”.

Nurses, pharmacists, and physicians suggested several ways to access the data collected by mHealth interventions. Some HCPs posited that they should be able to access the data through electronic medical records (EMR). A pharmacist proposed, “if there’s a possibility, even securely, to be able to take that information and put it in the EMR securely”. Another method of accessing mHealth data with HCPs is via the patient’s phone. A pharmacist with experience in mHealth observed, “I’ve had a couple of patients now who brought in their app and opened it up and I could look at their history and the results and I would go through it with them and it works great because I could tell them right there”.

#### *5.3.3.2 Allowing HCPs to communicate with patients and other HCPs is beneficial*

The HCP interface could be used to enhance communication between HCPs. When asked about the current practice regarding communication with physicians and specialists, one nurse who was monitoring patients through mHealth stated that patients identified their primary care physician during enrollment. Then, “once a month we will send out their PCP a monthly report of the biometric readings. If a patient is going to a GP or a respirologist and there's a concern that we have regarding their current health status with their COPD, we will do that letter and fax it to their appointments along with their biometric readings”. This thought was reinforced by others, as in this pharmacist’s statement, “if a pharmacist was kind of monitoring this and they were able to kind of do up like a consult letter kind of to send to the physician before the patient went to their physician, that would definitely be beneficial”. A nurse talked about streamlining patient requisitions via the HCP interface: “if we were able to have patient requisitions ahead of time...

that could cut out a visit and just a follow-up phone call for results, reports, treatment, if necessary".

Some HCPs put forward a feature that would allow them to opt in and receive a notification based on set criteria. A few HCPs stated that this could enable the healthcare provider to "receive the alerts if they (patients) are then outside pre-set parameters". When setting parameters, one nurse with experience in mHealth stressed the importance of "Realistic parameters for readings so that our patients are not alerting constantly. And number two:.. when I receive an alert I have got clinical algorithms to manage it". Some pharmacists recommended getting a notification for medication adherence, as in "getting a notification, like, for two weeks of missed therapy, would be very interesting to me".

To follow up on these notifications, a nurse commented on her patients who were enrolled in an mHealth intervention for COPD management

> *We would phone them or they would phone us if need be. It would be patient-specific for sure. Somebody who is well, somewhat well, who didn't do a session for a couple of days, you know, maybe we'd let it slide. But somebody who you know had been unwell for a few days and if they didn't do their health session, say by mid-morning, maybe you'd might call them and say, are you okay? What's going on?*

Similarly, a physician with experience in mHealth interventions noted, "ensure that whatever is going on with the patient there's an ability for them to have someone to have access to reassure them if they get upset".

#### *5.3.3.3 The educational component is valuable*

A few pharmacists and physicians recommended including current best practices and guidelines on COPD management. A physician reported: "would need to have an educational component, guidelines, you know, to remind me, of the Primary Care Guidelines…".

#### *5.3.3.4 Remunerating HCPs is a possibility*

The HCP interface can be used to deliver existing COPD adherence programs that are funded by the government or insurers. For example, pharmacists in NL get a time reimbursement if they complete the COPD adherence initial and follow-up consultations. One pharmacist indicated that the program is underused because of the time required to determine eligible patients and remember to follow up with them, as in

> *This is paid intervention, but the uptake is next-to-nothing because it is so hard to manage... For us to try to remember all that and remember to go get a manual form on top of that, it's tough...I need to manually remember within two weeks and go through these lists of questions. And then, within two months afterwards, which is even harder...I don't remember what I had for breakfast, let alone in two months, to call a person and do this again.*

The pharmacist surmised that the uptake of the medication adherence program would be higher if it was automated via an mHealth intervention "there's nothing like incentivizing a pharmacist to say, this is a good technology for you because it will make this programme very easy...if this were automated for a pharmacist, the likelihood of doing this type of a follow-up would be much higher".

## 5.4 Discussion

### 5.4.1 Principal Findings

This qualitative study found that HCPs and patients had several recommendations regarding the content of an mHealth intervention to assist in the management of COPD. Potential users brought forward several components that could support them in the future. This interest and the numerous suggestions from HCPs and patients with COPD indicate the readiness for using mHealth for COPD management.

To optimize the successful implementation of mHealth interventions, it is important to consider the perceived facilitators and barriers to mHealth adoption for COPD management that were published by our research group (Alwashmi et al., 2019a; Alwashmi et al., 2019b). The main facilitators to mHealth adoption are possible health benefits for patients, ease of use, educating patients and their HCPs, credibility, and reducing the cost to the healthcare system. Alternatively, the barriers to adoption are technical issues, privacy and confidentiality issues, lack of awareness, lack of interest, potentially limited uptake from the elderly, potential limited connection between patients and HCPs, and finances (Alwashmi et al., 2019a; Alwashmi et al., 2019b).

Our thoughts, based on the data, are that both HCPs and patients recommend tailoring the mHealth intervention based on the patient's unique needs and preferences. The mHealth intervention could potentially enhance COPD management using several features; most importantly, by collecting relevant subjective and objective data then using them to tailor COPD management based on the patient's unique needs. This collaborative and human-centered approach is not feasible without having a HCP interface to communicate and monitor the patients.

### 5.4.2 Comparison with Prior Work

Our study provides a novel and meaningful contribution to the literature. A few prior studies have specifically examined the features of mHealth among potential users, but in this case, we included HCPs and patients with COPD. We included consideration regarding a HCP interface that has not been reported previously in the context of mHealth for COPD management. Additionally, we discussed the use of compatible medical devices for COPD management.

Some of the features presented in this study confirm findings by previous research, such as the importance of education, self-monitoring, reminders, and communication between patients and HCPs (Kim & Lee, 2017; Korpershoek et al, 2018; Sobnath et al, 2017). In addition, we identify other potentially useful functions such as using various medical devices, including family members, and rewarding patients and HCPs. Previous researchers recommended including a larger sample of HCPs with more mHealth experience in future studies (Korpershoek et al., 2018).

Collecting baseline information was recommended by many HCPs. This information is vital for tracking patients' progress, and it can also be used to assist in monitoring patients to prevent exacerbations (Alwashmi et al., 2016). Addtionally, many researchers are utilizing smartphones for health research (Dorsey et al., 2017). Data collected via mHealth can be paired with other data sources from the patient's medical records or genetic makeup to expand our understanding of the etiology of COPD.

As suggested by Kim & Lee (2017), patients and HCPs should support the use of medical devices that automate data generation and transmission, as this could lead to increased compliance with the mHealth intervention. We elaborate on the use and frequency of several devices relevant to COPD management, including spirometers, pulse oximeters and medication adherence devices. Nuvoair® and AioCare® are two examples of portable spirometers that could be beneficial for COPD monitoring. The use of a patch biosensor, VitalPatch®, for measuring vital signs continuously could be beneficial for continuous unobtrusive patient monitoring (Selvaraj et al., 2018).

Advancements in mobile technology have improved how we track and enhance medication adherence. Both AiCure® and emocha mobile health® utilized artificial intelligence technology for facial recognition to determine if a patient takes and swallows medication (Holzman et al., 2018; Labovitz et al., 2017). Furthermore, a few companies such as propeller health®, Adherium®, and Cohero Health® are manufacturing medication adherence devices to provide an objective measure of adherence (Adams et al., 2017; Gregoriano et al., 2017; Hollenbach et al., 2017). These medication adherence devices have the potential to be used in assisting with improving the technique of inhaled medications (Kuipers et al., 2019).

A recurrent need was that mHealth interventions can be used to deliver an action plan to assist in COPD management. However, Korpershoek et al. (2018) stated that providing medical advice through mobile devices can be unsafe due to the large heterogeneity in patients and symptoms. Recent studies have shown that a machine-learning approach has the potential to assist in the management of COPD (Orchard et al., 2018; Swaminathan et al., 2017). While the action plan could increase patient autonomy, it will need extensive research on its safety, efficacy, and implications for COPD management.

Our findings are in agreement with Korpershoek et al. (2018), who stated that patients' needs regarding COPD management vary widely. The need for personalization, stemming from the individuality of patients, is an important finding. We expand on these findings by including data from both HCPs and patients about their preferences regarding the potential frequency of entering information, follow-up, and performing medical tests via compatible medical devices.

Some HCPs recommended using the mHealth intervention to remind patients about their appointments. The mHealth intervention could be used to automate scheduling and to remind patients about their appointments. Furthermore, Leavens et al. (2019) stated that rideshare services via smartphones may represent a relatively low-cost means for increasing study retention. Similarly, these ridesharing services can be integrated into the mHealth intervention to avoid missed appointments. Other researchers also found that rewarding patients via self-affirmations can successfully increase adherence to recommended health goals in the context of an mHealth app (Springer et al., 2018).

Sobnath et al. (2017) systematically reviewed the literature and app stores to identify features that can be considered in the initial design of a COPD support tool to improve healthcare services and patient outcomes. Features such as a social networking tool, personalized education, feedback, e-coaching, and psychological motivation to enhance behavioral change were found to be missing in many of the downloaded apps (Sobnath et al., 2017). A recent systematic review highlighted the effectiveness of mHealth apps that use CBT principles (Rathbone et al., 2017). Another important feature for a COPD support tool is the self-management of physical activity. Improvement of physical activity levels can result in better physical functioning, less dyspnea, higher quality of life, and lower risks for exacerbation-related hospitalization and mortality (Sobnath et al., 2017).

To stimulate information exchange between patients and HCPs, we included features of a HCP interface. Our findings echo some of the HCP interface features reported by Sobnath et al.

(2017), which include monitoring medication adherence and other features such as device tracking, patient training, managing clinic visits, and providing advice on lifestyle management. Korpershoek et al. (2018) found that both patients and their HCPs have doubts regarding information exchange between patients and HCPs through mobile devices. However, they did not expand on these doubts. We included qualitative quotes to expand on these insights.

### 5.4.3 Strengths and Limitations

This study has several strengths. First, this research is based on a diverse sample of participants. It includes various perspectives by presenting the views of patients, nurses, pharmacists, and physicians, including a respirologist. This human-centered approach ensures that the needs and challenges of different people involved in the management of COPD can be considered before developing an mHealth intervention. Second, some participants had experience in using an mHealth intervention to manage COPD, which further increases the richness of the data. Third, all the interviews were conducted in a similar manner to ensure consistency during the data collection and analysis. Finally, mHealth is particularly important in geographic locations with a relatively large proportion of rural residents such as Newfoundland and Labrador. mHealth may enhance care provider access throughout sparsely populated rural areas. Newfoundland and Labrador have a substantial remote and rural population; therefore, our results may be more applicable to rural areas.

There were also several limitations. First, not all participants had experience with using mHealth. Thus, the perceptions of these participants were not based on actual interventions with patients. Second, we used only one data collection method, thus data collection was not triangulated. Conducting focus groups with some of the participants following the individual interviews could have yielded richer information, as participants would have been given the opportunity to compare their thoughts and confirm or expand upon each other's ideas. This would be a recommendation for a future study.

### 5.4.4 Implications for practice and recommendations for future research

The findings of this study provide valuable insights regarding the features of an mHealth intervention for COPD management. These findings may help various stakeholders who are planning to use mHealth interventions for COPD management.

Future studies would benefit from conducting focus groups with some of the participants following the individual interviews. Focus groups could yield richer information, as participants would be given the opportunity to compare their thoughts and confirm or expand upon each other's ideas. Furthermore, including the perspectives of allied HCPs, such as physiotherapists, social workers, and occupational therapists, would be beneficial to understand the perspectives of administrators (e.g., information technology managers) who may be able to identify some of the challenges with using mHealth for COPD management. After developing a prototype of these human-centered components, the authors recommend using a mixed methods framework for usability testing (Alwashmi et al., 2019c).

Future mHealth studies should explore the utility of the mHealth intervention in reducing exacerbations, reducing hospitalizations and improving the quality of life for patients with COPD. Specifically, additional research is required to investigate the effectiveness and safety of the mHealth intervention in COPD management. Guidelines are required to tailor components of the mHealth intervention and frequency of contact, and reminders are required. Lastly, cost-effectiveness analysis is required to assess the impact of mHealth interventions on healthcare resources.

## 5.5 Conclusions

Advances in smartphones, wearables, and other smart devices align well with the developing interests of using mHealth to assist in the management of COPD. Although there is interest in applying mHealth for COPD management, little attention has been paid to human-centered design features by future users of mHealth. The findings of this study suggest that COPD patients and their HCPs are receptive to using an mHealth intervention with multiple evidence-based components to manage COPD. These components include the use of subjective and objective data to tailor COPD management based on the patient's unique needs. These findings are important, as they elaborate on the process of data flow from patients and their HCPs using both a patient and a HCP interface. These human-centered features may aid in the successful implementation of mHealth interventions for COPD management. We recommend that those who develop mHealth interventions for COPD should consider the components highlighted in this study. Lessons from this study may also be applied to other chronic diseases.

## 5.6 References

Adams, S. A., Leach, M. C., Feudtner, C., Miller, V. A., & Kenyon, C. C. (2017). Automated adherence reminders for high risk children with asthma: a research protocol. JMIR research protocols, 6(3), e48.

Alwashmi, M., Hawboldt, J., Davis, E., Marra, C., Gamble, J., & Abu Ashour, W. (2016). The effect of smartphone interventions on patients with chronic obstructive pulmonary disease exacerbations: A systematic review and meta-analysis. JMIR mHealth and uHealth, 4(3), e105. doi:10.2196/mhealth.5921

Alwashmi, M. F., Fitzpatrick, B., Davis, E., Gamble, J. M., Farrell, J., & Hawboldt, J. (2019a). Perceptions of Health Care Providers Regarding a Mobile Health Intervention to Manage Chronic Obstructive Pulmonary Disease: Qualitative Study. JMIR mHealth and uHealth, 7(6), e13950.

Alwashmi, M. F., et al (2019b). Perceptions of COPD patients regarding a mobile health intervention to manage COPD: a Mixed Methods Study (Draft).

Alwashmi, M. F., Hawboldt, J., Davis, E., & Fetters, M. D. (2019c). The Iterative Convergent Design for Mobile Health Usability Testing: Mixed-Methods Approach. JMIR mHealth and uHealth, 7(4), e11656.

Barberan-Garcia, A. et al. "Effects And Barriers To Deployment Of Telehealth Wellness Programs For Chronic Patients Across 3 European Countries". Respiratory Medicine 108.4 (2014): 628-637. Web.

Beattie, M. P., Zheng, H., Nugent, C., & McCullagh, P. (2014). COPD lifestyle support through self-management (CALS). In Bioinformatics and Biomedicine (BIBM), 2014 IEEE International Conference on (pp. 1-7). IEEE.

Bender, B. (2014). Nonadherence in chronic obstructive pulmonary disease patients: What do we know and what should we do next? Current Opinion in Pulmonary Medicine, 20(2), 132-137. doi:10.1097/MCP.0000000000000027

Bischoff, E. W., Hamd, D. H., Sedeno, M., Benedetti, A., Schermer, T. R., Bernard, S., ... & Bourbeau, J. (2011). Effects of written action plan adherence on COPD exacerbation recovery. Thorax, 66(1), 26-31.

Brinkman, S., & Kvale, S. (2015). Interviews: Learning the craft of qualitative research interviewing (3rd ed.). Los Angeles: Sage.

Canadian Institute for Health Information. (2008). Health indicators.http://www.webcitation.org/76gVKOWKJ

Creswell, J. W. (2016). 30 essential skills for the qualitative researcher. Los Angeles ; London; New Delhi ; Singapore ; Washington DC: Sage.

Combley, R. (Ed.). (2011). Cambridge business English dictionary. Cambridge University Press.

Damhus, C. S., Emme, C., & Hansen, H. (2018). Barriers and enablers of COPD telerehabilitation - a frontline staff perspective. International Journal of Chronic Obstructive Pulmonary Disease, 13, 2473-2482. doi:10.2147/COPD.S167501

Dennison, L., Morrison, L., Conway, G., & Yardley, L. (2013). Opportunities and challenges for smartphone applications in supporting health behavior change: Qualitative study. Journal of Medical Internet Research, 15(4), e86. doi:10.2196/jmir.2583

Department of Health, The Rt Hon Andrew Lansley CBE. Research and Innovation in Health and Social Care. 2012. GPs to prescribe apps for patients URL: https://www.gov.uk/government/news/gps-to-prescribe-apps-for-patients [accessed 2015-06-03] [WebCite Cache]

DiDonato, K. L., Liu, Y., Lindsey, C. C., Hartwig, D. M., & Stoner, S. C. (2015). Community pharmacy patient perceptions of a pharmacy-initiated mobile technology app to improve adherence. International Journal of Pharmacy Practice, 23(5), 309-319. doi:10.1111/ijpp.12168

Dorsey, E. R., McConnell, M. V., Shaw, S. Y., Trister, A. D., & Friend, S. H. (2017). The use of smartphones for health research. Academic Medicine, 92(2), 157-160.

Emerson, R. W. (2015). Convenience sampling, random sampling, and snowball sampling: How does sampling affect the validity of research? Journal of Visual Impairment & Blindness, 109(2), 164-168. doi:10.1177/0145482X1510900215

Global Initiative for Chronic Obstructive Lung Disease. (2019). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease. Retrieved from http://www.goldcopd.com/uploads/users/files/GOLD_Report_2014_Oct30.pdf

Gregoriano, C., Dieterle, T., Dürr, S., Arnet, I., Hersberger, K. E., & Leuppi, J. D. (2017). Impact of an electronic monitoring intervention to improve adherence to inhaled medication in patients with asthma and chronic obstructive pulmonary disease: study protocol for a randomized controlled trial. JMIR research protocols, 6(10), e204.

Guest, G., MacQueen, K. M., & Namey, E. E. (2012). Applied thematic analysis. Los Angeles: Sage.

Heffernan, K. J., Chang, S., Maclean, S. T., Callegari, E. T., Garland, S. M., Reavley, N. J., et al. (2016). Guidelines and recommendations for developing interactive eHealth apps for complex messaging in health promotion. JMIR mHealth and uHealth, 4(1), e14. doi:10.2196/mhealth.4423

Hollenbach, J. P., Cushing, A., Melvin, E., McGowan, B., Cloutier, M. M., & Manice, M. (2017). Understanding clinicians' attitudes toward a mobile health strategy to childhood asthma management: a qualitative study. Journal of Asthma, 54(7), 754-760.

Holzman, S. B., Zenilman, A., & Shah, M. (2018, April). Advancing patient-centered care in tuberculosis management: a mixed-methods appraisal of video directly observed therapy. In Open forum infectious diseases (Vol. 5, No. 4, p. ofy046). US: Oxford University Press.

Hopkins, Israel Green|Dunn, Kelly|Bourgeois, Fabienne|Rogers, Jayne|Chiang, Vincent W. (2016). From development to implementation—A smartphone and email-based discharge follow-up program for pediatric patients after hospital discharge. Health Care: The Journal of Delivery Science and Innovation, 4(2), 109-115. doi:10.1016/j.hjdsi.2015.11.003

International Organization for Standardization, (ISO). (2010). Ergonomics of human-system interaction - part 210: Human-centred design for interactive systems (ISO 9241-210:2010)

Jo, S., & Park, H. (2016). Development and evaluation of a smartphone application for managing gestational diabetes mellitus. Healthcare Informatics Research, 22(1), 11-21. doi:10.4258/hir.2016.22.1.11

Joe, J., & Demiris, G. (2013). Older adults and mobile phones for health: A review. Journal of Biomedical Informatics, 46(5), 947-954. doi:10.1016/j.jbi.2013.06.008

Johnston, K., Grimmer-Somers, K., Young, M., Antic, R., & Frith, P. (2012). Which chronic obstructive pulmonary disease care recommendations have low implementation and why? A pilot study. BMC research notes, 5(1), 652.

Juen, J., Qian Cheng, & Schatz, B. (2015). A natural walking monitor for pulmonary patients using mobile phones. IEEE Journal of Biomedical and Health Informatics, 19(4), 1399-1405. doi:10.1109/JBHI.2015.2427511

Kelly, S. Donnelly and B. Caulfield, "Smartphone derived movement profiles to detect changes in health status in COPD patients - A preliminary investigation," 2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Milan, 2015, pp. 462-465.

Kim, B. Y., & Lee, J. (2017). Smart devices for older adults managing chronic disease: a scoping review. JMIR mHealth and uHealth, 5(5), e69.

Kocsis, M. Vasilopoulou, A. Tsopanoglou, A. Papaioannou and I. Vogiatzis, "Telemonitoring system for home rehabilitation of patients with COPD," E-Health and Bioengineering Conference (EHB), 2015, Iasi, 2015, pp. 1-4.

Korpershoek, Y. J. G., Vervoort, S. C. J. M, Trappenburg, J. C. A., & Schuurmans, M. J. (2018). Perceptions of patients with chronic obstructive pulmonary disease and their health care providers towards using mHealth for self-management of exacerbations: A qualitative study. BMC Health Services Research, 18(1), 1-13. doi:10.1186/s12913-018-3545-4

Kuipers, E., Poot, C. C., Wensing, M., Chavannes, N. H., de Smet, P. A., & Teichert, M. (2019). Self-Management Maintenance Inhalation Therapy With eHealth (SELFIE): Observational Study on the Use of an Electronic Monitoring Device in Respiratory Patient Care and Research. Journal of medical Internet research, 21(5), e13551.

Labovitz, D. L., Shafner, L., Reyes Gil, M., Virmani, D., & Hanina, A. (2017). Using artificial intelligence to reduce the risk of nonadherence in patients on anticoagulation therapy. Stroke, 48(5), 1416-1419.

Leavens, E. L. S., Stevens, E. M., Brett, E. I., Molina, N., Leffingwell, T. R., & Wagener, T. L. (2019). Use of Rideshare Services to Increase Participant Recruitment and Retention in Research: Participant Perspectives. Journal of medical Internet research, 21(4), e11166.

Leech, N. L., & Onwuegbuzie, A. J. (2008). Qualitative data analysis: A compendium of techniques and a framework for selection for school psychology research and beyond. School psychology quarterly, 23(4), 587.

Leiva-Fernández, José et al. "Efficacy Of A Multifactorial Intervention On Therapeutic Adherence In Patients With Chronic Obstructive Pulmonary Disease (COPD): A Randomized Controlled Trial".BMC Pulmonary Medicine 14.1 (2014): n. pag. Web.

Macdonald, G. G., Townsend, A. F., Adam, P., Li, L. C., Kerr, S., McDonald, M., et al. (2018). eHealth technologies, multimorbidity, and the office visit: Qualitative interview study on the perspectives of physicians and nurses. Journal of Medical Internet Research, 20(1), e31. doi:10.2196/jmir.8983

Maxwell, J. A. (2013). Qualitative research design (3. ed. ed.). Los Angeles [u.a.]: Sage.

Mehdi Najafzadeh, Carlo A Marra, Larry D Lynd, Mohsen Sadatsafavi, J Mark FitzGerald, Bruce McManus, et al. (2012). Future impact of various interventions on the burden of COPD in Canada: A dynamic population model. PLoS One, 7(10), e46746. doi:10.1371/journal.pone.0046746

Mendiola, M. F., Kalnicki, M., & Lindenauer, S. (2015). Valuable features in mobile health apps for patients and consumers: content analysis of apps and user ratings. JMIR mHealth and uHealth, 3(2), e40.

Merriam, S. B., & Tisdell, E. J. (2015). Qualitative research (Fourth edition. ed.). US: Jossey-Bass.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). Qualitative data analysis. Los Angeles, Calif: Sage.

Miller, D., Steele Gray, C., Kuluski, K., & Cott, C. (2015). Patient-centered care and patient-reported measures: Let's look before we leap. The Patient, 8(4), 293. doi:10.1007/s40271-014-0095-7

Nabhani-Gebara, S., Kayyali, R., Philip, N., Pierscionek, B., Sobnath, D., Kaimakamis, E., ... & D'Arcy, S. (2014, November). WELCOME project: What do stakeholders want? In depth analysis of COPD patients, carers and healthcare professional views. In 2014 4th International Conference on Wireless Mobile Communication and Healthcare-Transforming Healthcare Through Innovations in Mobile and Wireless Technologies (MOBIHEALTH) (pp. 365-368). IEEE.

Nelson, L. A., Mayberry, L. S., Wallston, K., Kripalani, S., Bergner, E. M., & Osborn, C. Y. (2016). Development and usability of REACH: A tailored theory-based text messaging intervention for disadvantaged adults with type 2 diabetes. JMIR Human Factors, 3(2), e23. doi:10.2196/humanfactors.6029

Nguyen, H. Q., Gill, D. P., Wolpin, S., Steele, B. G., & Benditt, J. O. (2009). Pilot study of a cell phone-based exercise persistence intervention post-rehabilitation for COPD. International journal of chronic obstructive pulmonary disease, 4, 301.

Noah, B., Keller, M. S., Mosadeghi, S., Stein, L., Johl, S., Delshad, S., ... & Spiegel, B. M. (2018). Impact of remote patient monitoring on clinical outcomes: an updated meta-analysis of randomized controlled trials. NPJ Digital Medicine, 1(1), 20172.

Orchard, P., Agakova, A., Pinnock, H., Burton, C. D., Sarran, C., Agakov, F., & McKinstry, B. (2018). Improving Prediction of Risk of Hospital Admission in Chronic Obstructive Pulmonary Disease: Application of Machine Learning to Telemonitoring Data. Journal of medical Internet research, 20(9), e263.

Patton, M. Q. (2015). Qualitative research & evaluation methods: Integrating theory and practice Sage Publications.

Rathbone, A. L., Clarry, L., & Prescott, J. (2017). Assessing the efficacy of mobile health apps using the basic principles of cognitive behavioral therapy: systematic review. Journal of medical Internet research, 19(11), e399.

Rubin, H. J., & Rubin, I. S. (2012). Qualitative interviewing: The art of hearing data (Third edition ed.). Los Angeles: Sage.

Saldaña, J. (2016). The coding manual for qualitative researchers (3E [3th edition] ed.). Los Angeles ; London ; New Delhi ; Singapore ; Washington, DC: SAGE.

Sarkar, U., Gourley, G., Lyles, C., Tieu, L., Clarity, C., Newmark, L., et al. (2016). Usability of commercially available mobile applications for diverse patients. Journal of General Internal Medicine, 31(12), 1417-1426. doi:10.1007/s11606-016-3771-6

Sedeno, M. F., Nault, D., Hamd, D. H., & Bourbeau, J. (2009). A self-management education program including an action plan for acute COPD exacerbations. COPD: Journal of Chronic Obstructive Pulmonary Disease, 6(5), 352-358.

Selvaraj, N., Nallathambi, G., Moghadam, R., & Aga, A. (2018, July). Fully Disposable Wireless Patch Sensor for Continuous Remote Patient Monitoring. In 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) (pp. 1632-1635). IEEE.

Smith, S. A., Claridy, M. D., Smith Whitehead, M., Sheats, J. Q., Yoo, W., Alema-Mensah, E. A., et al. (2015). Lifestyle modification experiences of African American breast cancer survivors: A needs assessment. JMIR Cancer, 1(2), e9. doi:10.2196/cancer.4892

Sobnath, D. D., Philip, N., Kayyali, R., Nabhani-Gebara, S., Pierscionek, B., Vaes, A. W., ... & Kaimakamis, E. (2017). Features of a mobile support app for patients with chronic obstructive pulmonary disease: literature review and current applications. JMIR mHealth and uHealth, 5(2), e17.

Spina, Gabriele et al. "Identifying Physical Activity Profiles In COPD Patients Using Topic Models".IEEE Journal of Biomedical and Health Informatics 19.5 (2015): 1567-1576. Web.

Springer, A., Venkatakrishnan, A., Mohan, S., Nelson, L., Silva, M., & Pirolli, P. (2018). Leveraging self-affirmation to improve behavior change: a mobile health app experiment. JMIR mHealth and uHealth, 6(7), e157.

Steele Gray, C., Khan, A. I., Kuluski, K., McKillop, I., Sharpe, S., Bierman, A. S., et al. (2016). Improving patient experience and primary care quality for patients with complex chronic disease using the electronic patient-reported outcomes tool: Adopting qualitative methods into a user-centered design approach. JMIR Research Protocols, 5(1), e28. doi:10.2196/resprot.5204

Steinhubl, S. R., Muse, E. D., & Topol, E. J. (2015). The emerging field of mobile health. Science Translational Medicine, 7(283), 283rv3.

Suh, E. , Mandal, S., & Hart, N. (2013). Admission prevention in COPD: Non-pharmacological management. BMC Medicine, 11(1)

Swaminathan, S., Qirko, K., Smith, T., Corcoran, E., Wysham, N. G., Bazaz, G., ... & Gerber, A. N. (2017). A machine learning approach to triaging patients with chronic obstructive pulmonary disease. PloS one, 12(11), e0188532.

Tabak, Monique, Harm op den Akker, and Hermie Hermens. "Motivational Cues As Real-Time Feedback For Changing Daily Activity Behavior Of Patients With COPD". Patient Education and Counseling 94.3 (2014): 372-378. Web.

Taylor, J., Coates, E., Wessels, B., Mountain, G., & Hawley, M. S. (2015). Implementing solutions to improve and expand telehealth adoption: Participatory action research in four community healthcare settings. BMC Health Services Research, 15(1), 529. doi:10.1186/s12913-015-1195-3

Taylor, Johanna et al. "Implementing Solutions To Improve And Expand Telehealth Adoption: Participatory Action Research In Four Community Healthcare Settings". BMC Health Services Research 15.1 (2015): n. pag. Web.

Theriault L, Hermus G, Goldfarb D, Stonebridge C, Bounajm F. (2012). Cost risk analysis for chronic lung disease in Canada. Retrieved http://www.conferenceboard.ca/e-library/abstract.aspx?did=4585

Triantafyllidis, Andreas|Velardo, Carmelo|Chantler, Tracey|Shah, Syed Ahmar|Paton, Chris|Khorshidi, Reza|Tarassenko, Lionel|Rahimi, Kazem. (2015). A personalised mobile-based home monitoring system for heart failure: The SUPPORT-HF study. International Journal of Medical Informatics, 84(10), 743-753. doi:10.1016/j.ijmedinf.2015.05.003

Upshur, R. E. G., & Tracy, S. (2008). Chronicity and complexity: Is what's good for the diseases always good for the patients? Canadian Family Physician Medecin De Famille Canadien, 54(12), 1655. Retrieved from MEDLINE database. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/19074692

Vorrink, S., Kort, H. H., Troosters, T., & Lammers, J. J. (2016). A mobile phone app to stimulate daily physical activity in patients with chronic obstructive pulmonary disease: Development, feasibility, and pilot studies. JMIR Mhealth and Uhealth, 4(1), 156. doi:10.2196/mhealth.4741

Wang CH, Chou PC, Joa WC, et al. Mobile-phone-based home exercise training program decreases systemic inflammation in COPD: A pilot study. BMC Pulm Med. 2014;14:142-2466-14-142. doi: 10.1186/1471-2466-14-142 [doi].

Wolcott, H. F. (2008). Writing up qualitative research. Sage Publications.

Wood-Baker, R., McGLONE, S., Venn, A., & Walters, E. H. (2006). Written action plans in chronic obstructive pulmonary disease increase appropriate treatment for acute exacerbations. Respirology, 11(5), 619-626.

World Health Organization. (2011). mHealth: new horizons for health through mobile technologies. mHealth: new horizons for health through mobile technologies.

World Health Organization (2007). Global Surveillance, Prevention and Control of Chronic Respiratory Diseases: A Comprehensive Approach. URL: http://www.who.int/gard/publications/GARD%20Book%202007.pdf [accessed 2015-05-13] [WebCite Cache]

Yin, R. K. (2011). Qualitative research from start to finish. New York, NY.

Zhang, J., Song, Y., & Bai, C. (2013). MIOTIC study: A prospective, multicenter, randomized study to evaluate the long-term efficacy of mobile phone-based internet of things in the management of patients with stable COPD. International Journal of Chronic Obstructive Pulmonary Disease, 8, 433-438. doi:10.2147/COPD.S50205

# Chapter 6: The Iterative Convergent Design for Mobile Health Usability Testing: Mixed Methods Approach

## Preface

Health care professional and patients stressed the importance of usability to improve the uptake of mHealth interventions. This chapter provides a new mixed-methods design to enhance the usability of an mHealth intervention. A version of this chapter has been published in the Journal of Medical Internet Research (JMIR) - mHealth and uHealth: Alwashmi, M. F., Hawboldt, J., Davis, E., & Fetters, M. D. (2019). The iterative convergent design for mobile health usability testing: mixed-methods approach. JMIR mHealth and uHealth, 7(4), e11656. I completed the first draft and revised it according to the suggestions of co-authors and reviewers. Dr. Michael Fetters, who is the co-Editor of the Journal of Mixed Methods Research, suggested the general research topic and provided feedback on the manuscript. He also helped revise the original manuscript to make the argument clearer. Dr. John Hawboldt and Dr. Erin Davis reviewed the manuscript and provided revision suggestions.


## Abstract

Although patients express an interest in using mobile health (mHealth) interventions to manage their health and chronic conditions, many current mHealth interventions are difficult to use. Usability testing is critical for the success of novel mHealth interventions. Researchers recognize the utility of using qualitative and quantitative approaches for usability testing, but many mHealth researchers lack the awareness of integration approaches from advances in mixed methods research that can add value to mHealth technology.

As efficient usability testing proceeds iteratively, we introduce a novel mixed methods design developed specifically for mHealth researchers. The iterative convergent mixed methods

design involves simultaneous qualitative and quantitative data collection and analysis that continues cyclically through multiple rounds of mixed methods data collection and analysis until the mHealth technology under evaluation is found to work to the satisfaction of the researcher. In cyclical iterations, early development is more qualitatively driven but progressively becomes more quantitatively driven. Using this design, mHealth researchers can leverage mixed methods integration procedures in the research question, data collection, data analysis, interpretation, and dissemination dimensions.

This study demonstrates how the iterative convergent mixed methods design provides a novel framework for generating unique insights into multifaceted phenomena impacting mHealth usability. Understanding these practices can help developers and researchers leverage the strengths of an integrated mixed methods design.

## 6.1 Introduction

Published studies indicate that mobile health (mHealth) interventions are beneficial for patients across various diseases and age groups (Joe & Demiris, 2013; Juen et al., 2015; Zhang et al., 2013; Alwashmi et al., 2016). Academics and clinicians have an increasing interest in harnessing these mHealth interventions to improve health outcomes. Although patients express an interest in using mHealth to manage their health and chronic conditions, many current mHealth interventions are difficult to use (Sarkar et al., 2016). Hence, developers of mHealth need efficient and effective approaches for development, but usability research methodology remains in a relatively nascent stage of development (Carayon et al., 2015). Usability testing is critical for the success of novel mHealth interventions. Although researchers recognize the utility of using qualitative and quantitative approaches for usability testing, many mHealth researchers lack the awareness of integration approaches from advances in mixed methods research (MMR) (Fetters & Molina-Azorin, 2017) that can add value to mHealth technology.

This paper advances the existing literature about the combined use of qualitative and quantitative research for mHealth by advancing a specific, integrated approach to mixed methods design appropriate to mHealth. When using qualitative and quantitative procedures without integration, researchers miss the opportunity for added value. Mixed methods methodologists express this as 1+1=2, as the quantitative and qualitative procedures are conducted as 2 independent studies with no particular synergy (Fetters, 2018). By using integrated procedures identified in the field of MMR, researchers can aspire for and achieve added value, as expressed by 1+1=3 (Fetters, 2018; Fetters & Freshwater, 2015).

The purpose of this paper is to articulate and illustrate the features of an iterative convergent mixed methods design. As efficient usability testing proceeds iteratively, we introduce a novel mixed methods design developed specifically for mHealth researchers. It offers a novel framework to generate unique insights into multifaceted phenomena related to mHealth usability. Understanding these practices can help developers and researchers leverage the strengths of an integrated mixed methods design.

### 6.1.1 Background

#### *6.1.1.1 Mobile Health*

Effective health care strategies are required to ensure the right patient receives the right treatment at the right time. Advancements in mobile phones and tablets have led to the emergence of mHealth. The Global Observatory for eHealth of the World Health Organization defines mHealth as "medical and public health practice supported by mobile devices, such as mobile phones, patient monitoring devices, personal digital assistants, and other wireless devices" (World Health Organization, 2011). Recent advances allow seamless integration between smartphones and medical devices. This integration enables smartphones to store and analyze objective measurements such as heart rate, lung volume, and medication adherence. Advancements in machine learning and artificial intelligence have the potential to use these measurements, in combination with data collected via smartphones, to improve our understanding of disease etiology (Fogel & Kvedar, 2018; Watson, n.d.).

The significance of mHealth is highlighted by its ability to deliver timely care over distance to manage diseases. It is particularly important for rural areas with limited access to health care (Källander et al., 2013; Aranda-Jan et al., 2014). Moreover, mHealth strategies can enhance treatment outcomes while mitigating health care costs (Vashist et al., 2015; Hayes et al., 2014). Hayes et al. (2014) illustrated why mHealth could reduce physician visits, resource consumption, and emergency room visits. The literature continues to evolve on applications of mHealth. For example, several published studies indicate that mHealth interventions are beneficial for patients across various diseases and age groups (Joe & Demiris, 2013; Juen et al., 2015; Zhang et al., 2013; Alwashmi et al., 2016). However, research on the development and usability methodology of such interventions remains in a relatively early stage.

#### *6.1.1.2 Human-Centered Design*

The International Organization for Standardization (ISO) 9241-210 standard defines human-centered design (HCD) as “an approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques” (ISO, 2010). The ISO uses the term HCD instead of user-centered design as it” addresses impacts on a number of stakeholders, not just those typically considered as users” (ISO, 2010). However, in practice, these terms are often used synonymously.

HCD has 4 defined activity phases: (1) identify the user and specify the context of use, (2) specify the user requirements, (3) produce design solutions, and (4) evaluate design solutions against requirements. The process model of HCD as defined in ISO 9241-210 is illustrated in Figure 6.1.

Researchers advocate for involving patients during development who are going to use the mHealth intervention to meet the patient’s needs and facilitate successful uptake. Testing mHealth interventions with patients reveals preferences and concerns unique to the tested population (Carayon et al., 2015; Nelson et al., 2016; Gray et al., 2016). Developing an mHealth intervention with insights from stakeholders will potentially improve the process and outcome of mHealth interventions. The main goal of HCD is to increase the usability of mHealth technology.

This study offers an in-depth account of the HCD's fourth activity phase, evaluate design solutions against requirements. This clarifies that this framework intends to focus on usability testing as one component of the more extensive design process.

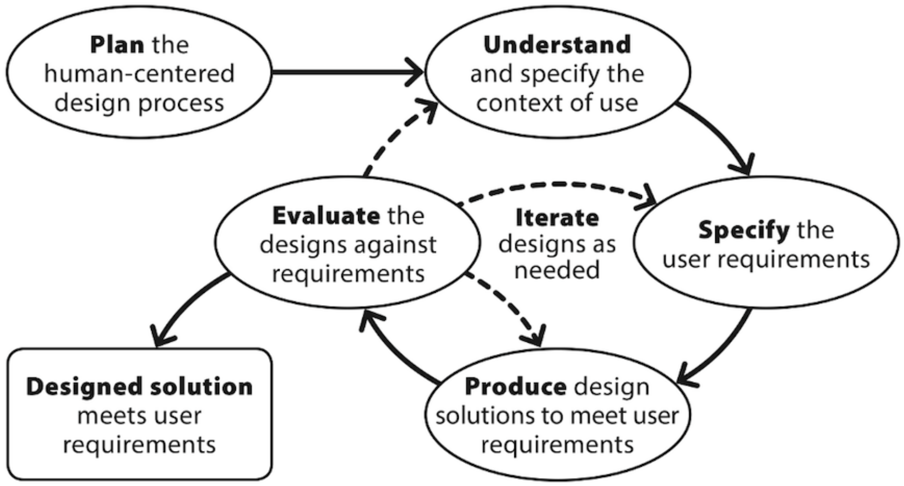



**Figure 6.1:** Human-centered design activity phases.

#### *6.1.1.3 Usability*

The ISO defines usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use (ISo, 2018). Although this definition was published in 1998, it has been updated in 2018 without any changes to the core concepts. The definition is widespread and generalizable (Goldberg et al., 2011; Bevan et al., 2015).

mHealth involves the interaction between multiple user groups through a system. As a result, the usability aspect is vital for the effective, efficient, and satisfactory use of mHealth interventions. Although patients express an interest in using mHealth to manage their health and chronic conditions, many mHealth interventions are not easy to use (Horton, 2008; Sarkar et al.,2016). Difficulty in using an mHealth intervention may limit the user retention rate. A high dropout rate is one of the most significant barriers to mHealth adoption (Mayberry et al., 2017;

Dorsey et al., 2017). The majority of mHealth app publishers (83%) have less than 10,000 users who have used the app at least once a month (Research2Guidance, 2018). These numbers are discouraging as according to a 2018 estimate, the average mHealth app costs $425,000 to develop (Research2Guidance, 2018). By putting a more significant emphasis on usability, iterative improvements can reduce costs and enhance the long-term use and adoption of mHealth interventions (Usability.gov, n.d. a; Ribeiro et al., 2016; Smith et al., 2015).

Researchers recommend frequent and iterative usability testing to respond to users' preferences, technical issues, and shortcomings (Hatink et al., 2016; Triantafyllidis et al., 2015; Nelson et al., 2016). It is also important to ensure that errors in understanding or using the intervention are addressed before testing the intervention in an efficacy trial (Lyles et al., 2014). A systematic review investigated the usability evaluation processes described in 22 studies related to mHealth applications (Zapata et al., 2015). The results suggest that the adoption of automated mechanisms could improve usability and stress the importance of adapting health applications to users' need (Zapata et al., 2015). Including insights from key users of mHealth has the potential to improve the process and the outcome of the intervention (Hopkins et al., 2016).

Contemporary iterative development methods, such as prototyping, reduce the challenges that evolve during the development lifecycle (Krug, 2014). Prototyping is defined as creating a simulation of the final mHealth technology that is used for testing before launch. Furthermore, researchers suggest including patients who are going to use the mHealth interventions to assist in the development of the intervention (Sarkar et al., 2016; Nelso et al., 2016; Gray et al., 2016; Zapata et al., 2015).

The ISO 9241-11 established usability standards (ISO, 2018). These standards provide a measure of patients' experienced usability. It focuses on effectiveness, efficiency, and satisfaction (ISO, 2018). It is easier to quantify effectiveness and efficiency compared with satisfaction. Brooke developed the System Usability Scale (SUS) (Brooke, 1996) and noted that "if there is an area in which it is possible to make more generalized assessments of usability, which could bear cross-system comparison, it is the area of subjective assessments of usability" (Brooke, 1996). Thus, the SUS was developed to quantify satisfaction (users' subjective reactions to using the system) (Brooke, 1996) . The SUS is an affordable and effective tool for assessing the usability of products (Brooke, 1996). It contains 10 statements that are answered on a 5-point Likert scale. Although this scale was developed in 1996, it is relevant and applicable to current research because it is short and easy to use. Many contemporary mHealth studies have been successful in combining both ISO and SUS to assess usability (Farinango et al., 2018; Gunter et al., 2016; Georgsson & Staggers, 2016). Table 6.1 describes the ISO 9241-11 usability constructs.

**Table 6.1:** Usability constructs and descriptions.

| Constructs[a] | Metrics | Description |
|---|---|---|
| Effectiveness | Time to learn and use | Time to read the scenarios and to begin performing tasks |
| | Data entry time | Time to enter the data necessary for the execution of a task |

| | | |
|---|---|---|
| | Tasks time | Time to accomplish given tasks |
| | Response time | Time of having the response to the requested information |
| | Time to install | Installation time of applications or its update |
| Efficiency | Number of errors | Number of errors made while reading scenarios and during the task execution |
| | Completion rate | The percentage of participants who correctly complete and achieve the goal of each task |
| Satisfaction | Usability score | The System Usability Questionnaire |

[a]adapted from Moumane et al. (2016).

#### *6.1.1.4 Mixed Methods Research*

MMR is gaining popularity and acceptance across disciplines and the world (Creswell, 2016). It draws from multiple scientific traditions and disciplinary backgrounds. MMR is defined as "the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches for the broad purposes of breadth and depth of understanding and corroboration" (Johnson et al., 2007). MMR combines both closed-ended response data (quantitative) and open-ended personal data (qualitative) (Creswell, 2016).

Although quantitative research historically has predominated in health sciences research, many contemporary phenomena in health care are difficult, if not impossible, to measure using quantitative methods alone (Curry & Nunez-Smith, 2015). The goal of qualitative research is to produce a deep understanding of a phenomenon. It can also be used to generate a hypothesis regarding a phenomenon, its precursors, and its consequences (Curry et al., 2009). When the study phenomenon of interest is multifaceted and complex, a mixed methods approach is appropriate (Curry & Nunez-Smith, 2015). The National Institutes of Health best practices guidelines and many mixed methods researchers advise distinguishing the quantitative purpose, the qualitative research questions, and the mixed methods questions (Creswell et al., 2011). Consequently, MMR can capitalize on the strengths of both methods, the depth of qualitative research and the breadth of quantitative research. The resulting mixed data can be integrated to balance the strengths and limitations of either method to provide a more comprehensive understanding under potentially complementary sources of evidence (Curry & Nunez-Smith, 2015).

Understanding the principles and practices of integration is essential for leveraging the strengths of MMR. Fetters and Molina-Azorin (2017) defined integration as the linking of qualitative and quantitative approaches and dimensions together to create a new whole or a more holistic understanding than achieved by either alone. Fetters et al. examined vital integration principles and practices in MMR (Fetters et al., 2013). They provide approaches to integrating both research procedures and data in the design, methods, interpretation, and reporting dimensions of research (Fetters et al., 2013). Table 6.2 provides the relevant dimensions of MMR integration and illustrates how researchers can integrate those dimensions. These dimensions are relevant to mHealth, and additional information about MMR dimensions is explained elsewhere (Fetters & Molina-Azorin, 2017). Through increasingly sophisticated approaches, MMR is viewed as an opportunity to address the highly complex, compelling, and even wicked research problems facing researchers in the health and social sciences (Metrens, 2014). Investigation of novel mHealth technologies is an important example of a highly complex research challenge that can benefit from a systematic mixed methods approach.

**Table 6.2:** Relevant dimensions of the mixed methods research integration.

| Integration dimensions[a] | Mixed methods researchers integrate by |
|---|---|
| Rationale dimension | Citing a rationale for conducting an integrated mixed methods research study (e.g., offsetting strengths and weaknesses, comparing, complementing or expanding, developing or building, and promoting social justice) |
| Study purpose, aims, and research questions dimension | Composing an overarching mixed methods research purpose and stating qualitative, quantitative, and mixed methods aims or multiple mixed methods aims with quantitative aims and qualitative questions |
| Research design dimension | Scaffolding the work in core (e.g., convergent, exploratory sequential, and explanatory sequential), advanced (e.g., intervention, case study, evaluation, and participatory), or emergent designs. |

| | |
|---|---|
| Sampling dimension | Sampling through the type, through the relationship of the sources of the qualitative and quantitative data (e.g., identical sample, nested sample, separate samples, and multilevel samples), and through the timing (e.g., same or different periods for collection of the qualitative and quantitative data) |
| Data collection dimension | Collecting both types of data with an intent relative to the mixed methods research procedures (e.g., comparing, matching, diffracting, expanding, constructing a case, connecting, building, generating and validating a model, or embedding). |

| | |
|---|---|
| Data analysis dimension | Analyzing both types of data using intramethod analytics (e.g., analyzing each type of data within the respective qualitative and quantitative methods and core integration analytics), using 1 or more core mixed methods analysis approach (e.g., by following a thread, spiraling, and back-and-forth exchanges), or employing advanced mixed methods analysis (e.g., qualitative to quantitative data transformation, quantitative to qualitative data transformation, creating joint displays, social network analysis, qualitative comparative analysis, repertory grid/other scale development techniques, geographic information systems mapping techniques, and iterative and longitudinal queries of the data). |
| Interpretation dimension | Interpreting the meaning of mixed findings (e.g., where there are related data and drawing metainferences or conclusions based on interpreting the qualitative and quantitative findings) and examining for the fit of the 2 types of data (e.g., confirmation, complementarity, expansion, or discordance). When the results conflict with each other, using procedures for handling the latter including reconciliation, initiation, bracketing, and exclusion. |

[a]adapted from Fetters and Molina-Azorin (2017).

#### *6.1.1.5 Importance of Mixed Methods in Usability Testing*

Usability is a complex phenomenon. It is challenging to investigate usability comprehensively using only quantitative methods or qualitative methods in isolation, so-called monomethod approaches (Carayon et al., 2015). The alternative to using a monomethod approach is using diverse methods to generate a complete picture and reveal hidden patterns and novel relationships between variables and concepts (Curry & Nunez-Smith, 2015). To identify and resolve usability issues, various researchers emphasize the importance of using multiple methods and sources of data (Nitsch et al., 2016; Nelson et al., 2016). Although many studies collect both quantitative and qualitative data to test usability(Sage et al., 2017; Beatty et al., 2018; Alnasser et al., 2018), mHealth researchers could benefit from advances being made for integration in mixed methods studies (Fetters et al., 2013; Creswell & Clark, 2018).

Despite the recognized and intuitive value of using mixed methods for mHealth usability testing, mixed methodologists have yet to articulate specific designs that guide the development and testing of mHealth interventions. A core MMR study design that is attractive for usability testing is the convergent design (Creswell & Clark, 2018). Also called by some authors as a concurrent parallel study (Tashakkori et al., 1998) or, historically, a concurrent triangulation design (Creswell et al., 2003), the convergent mixed methods design features the collection and analysis of both types of data and then merging of the data for the final interpretation (Creswell, 2015).

#### *6.1.1.6 The Iterative Convergent Mixed Methods Design*

Owing to the iterative nature of usability testing, we propose a new variation of the convergent design specifically for mHealth, namely, the iterative convergent mixed methods design. We define an iterative convergent mixed methods design as an approach involving simultaneous qualitative and quantitative data collection and analysis that continues cyclically through multiple rounds of mixed methods data collection and analysis until the mHealth technology under evaluation is found to work to the satisfaction of the researcher. In cyclical iterations, early development is more qualitatively driven but progressively becomes more quantitatively driven; see Figure 6.2 (Hesse-Biber & Johnson, 2015). Thus, the iterative convergent mixed methods design involves simultaneously collecting and analyzing qualitative and quantitative data and, as critically important, taking into consideration the iterative nature of mHealth technology development.

In the following, we articulate the features of an iterative convergent mixed methods design appropriate for mHealth intervention development and usability testing that incorporates an iterative process and is conducted according to the user's health care and usability needs. Leveraging a specific mixed methods design can help fully integrate the 2 forms of data to enhance the understanding of the usability of mHealth interventions.

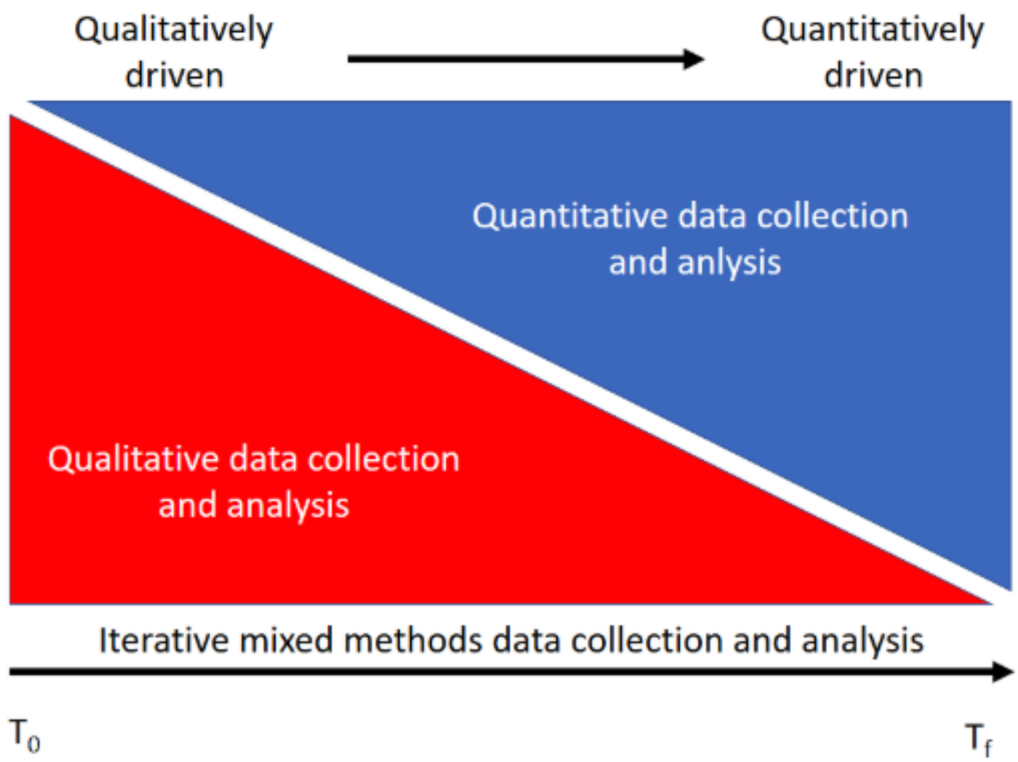



**Figure 6.2:** Evolution in an iterative convergent mixed methods design from qualitatively driven to quantitatively driven.

## 6.2 Methodology

Fetters et al recommend considering the design, data collection procedures, interpretation, and analysis for achieving integration in a mixed methods study (fetters et al., 2013). The iterative convergent design includes integration in various dimensions: the research aim/question, data collection, data analysis, and data interpretation. As illustrated in Figure 6.3, the results of each iteration inform further development of mHealth technology. These integration dimensions, as applied to usability testing, are discussed in more detail below.

### 6.2.1 Step 1: Integration in the Research Aim/Question Dimension

An iterative convergent mixed methods design should have an MMR aim as well as specific quantitative research aims and qualitative research questions.

#### *6.2.1.1 Mixed Methods Aim*

The mixed methods aim is to illustrate, explore, and measure how to improve the usability of an mHealth intervention. A mixed methods aim should imply both qualitative and quantitative data collection methods. For example, illustrate and explore imply qualitative data collection, whereas measure implies qualitative data collection (Fetters & Molina-Azorin, 2017).

#### *6.2.1.2 Quantitative Research Aims*

Appropriate quantitative research aims include measuring effectiveness, efficiency, and satisfaction, as illustrated in Table 6.3. These constructs provide a measure of patients' experienced usability. Effectiveness, efficiency, and satisfaction can be compared across iterations to identify the most usable mHealth technology.

**Table 6.3** Matching of the construct's quantitative variables and qualitative questions in a joint display depicting mixed methods of data collection.

| Construct | Quantitative variables | Qualitative questions |
|---|---|---|
| Effectiveness | Time to learn and use | How did you learn to use the app? How can we reduce the time it takes to learn the app? What was your experience using the app? How can we reduce the time it takes to use the app? |
| | Data entry time | How can we reduce the time it takes to enter the data? |
| | Tasks time | How can we reduce the time it takes to complete the task? |
| | Response time | How do you feel about the app response time? |
| | Time to install | What are your thoughts about the time it took to install the app? The time it took to pair the medical device, if applicable? |
| Efficiency | Number of errors | What can we do to help users avoid the same error? |
| | Completion rate | What can we do to enhance the completion rate? |

| | | |
|---|---|---|
| Satisfaction | Usability score | How often would you use the app? Why? Why not?; How do you feel about the complexity of the app?; How can we simplify it?; Do you have any recommendations to make the wording and interface easier to use? ; Would you need the support of a technical person to be able to use this system? How would you contact them: phone, email, or messaging? ; How did you find the integration of various functions in this app? How can we make it better?; How did you feel about the consistency of the app?; How can we simplify it?; Did you have any troubles when using the app? Where? How can we fix it? ; Did you feel confident when using the app? How can we make you more confident?; Did the app capture issues of importance to you?; Are there other ways to gather similar information? |

#### *6.2.1.2 Qualitative Research Questions*

As illustrated in Table 6.3, appropriate qualitative research questions include clarifying and characterizing our understanding of mHealth intervention usability. Qualitative inquiry is particularly valuable for understanding how and why a phenomenon occurs, a theory explaining a phenomenon, or the nature of someone's experience (Teherani et al., 2015). In usability testing, specific applications can include how and why participants make certain choices when using a prototype or their overall assessment of the utility. Usability testing may require or suggest a theory for its utility. The quality of the user's experience is critical for an mHealth developer who is creating a desirable user-friendly system.

A recent study by Beatty et al. (2018) illustrates the mixed methods process as they collected both quantitative and qualitative data to determine the usability of a mobile app for technology-facilitated home cardiac rehabilitation. Quantitative data included the SUS and task completion rate, whereas the qualitative data included questions about the functionality of the mobile app (Beatty et al., 2018).

### 6.2.2 Step 2: Integration in the Data Collection Dimension

During usability testing, users will be asked to provide feedback optionally on paper and, later, on working prototypes. Testing usability with 5 participants will generally be sufficient for identifying significant issues for each version (Nielsen, 2018). During each session, participants will be given specific tasks. Both quantitative and qualitative data will be collected during and after the completion of the tasks. Researchers have 3 key strategies for integration during data collection: matching, diffracting, and expanding.

#### *6.2.2.1 Matching*

The matching integration strategy involves intentionally asking qualitative questions that address the scales or constructs of quantitative instruments such that both instruments will elucidate data about the same concepts or domains (Fetters & Molina-Azorin, 2017). For example, the constructs of both the ISO standards and SUS used during quantitative data collection can be matched with similar or related qualitative questions to generate related quantitative and qualitative data, as illustrated in Table 6.3. A mixed methods data collection joint display includes the major constructs of inquiry in the first column. The latter 2 columns include the quantitative data, for example, scales or items, and the qualitative data, for example, qualitative questions or observation types. For example, Beatty et al. (2018) used matching by integrating the task completion time (quantitative) with asking "I noticed that the _____ feature took you longer than some of the others. Tell me more about that?" (qualitative). They also expanded on the SUS by asking open-ended questions regarding the user's experience with the mHealth intervention.

The qualitative questions in this table include both general and specific questions. Depending on the development needs, more general questions may be used initially, whereas later, more specific questions may be asked. When data become available, the same table structure can be populated with the findings; see Step 4: Integration in the Data Interpretation Dimension. The ordering of the columns is flexible according to specific project procedures.

#### *6.2.2.2 Diffracting*

The diffracting integration strategy involves intentionally asking qualitative questions that will address different aspects of the quantitative data, in the case of mHealth, the usability measure (Uprichard & Dawney, 2019). The intent is to obtain different cuts of data that will reveal information about different aspects of the usability that will not be addressed with the quantitative scales or items that are being collected (Uprichard & Dawney, 2019). Hence, for the ISO measures of effectiveness, efficiency, and satisfaction, qualitative questions might explore other facets, for example, animations, color patterns, sounds, and font size.

Diffracting can be used to address external factors to the user; such as the ease of connecting to the internet or connecting medical devices via Bluetooth. It is also important to develop an mHealth intervention that is energy efficient. mHealth interventions that require frequent charging of the smartphone or medical device are not recommended. Finally, developers should ensure that adequate resources are available to address medical and technical difficulties related to the mHealth intervention.

#### *6.2.2.3 Expanding*

The expanding integration strategy occurs when the findings from the 2 sources of data diverge and expand upon the phenomenon of interest by addressing both different aspects of a single phenomenon as well as a central phenomenon of interest (Fetters et al., 2013). Expansion involves intentionally asking qualitative questions that will be the same as the quantitative scales, while also measuring and asking qualitative questions that will address different aspects of usability. In essence, it reflects a hybrid strategy of using both matching, an area of overlap, and diffracting by looking at different aspects or facets of mHealth during the collection of data. Each of these integration strategies could be used effectively in usability testing.

#### *6.2.2.4 Quantitative Data Collection*

Current prototyping platforms, such as InVision and Adobe XD, integrate with Lookback to enable recording of the user's interaction with a smartphone. These allow recording of the participant's voice, nonverbal reactions, and mobile phone screen display. The researcher asks participants to complete a set of tasks and assess effectiveness, efficiency, and satisfaction. The researcher records the time to learn and use mHealth technology, data entry time, task completion time, response time, and time to install the mHealth technology. The researcher also records the number of errors and task completion rate. After completing the tasks, the researcher administers the SUS to assess the user's satisfaction with the mHealth technology.

#### *6.2.2.5 Qualitative Data Collection*

The methods appropriate for assessment generally involve semistructured interviews during or after the participant's use of the prototype. Researchers can utilize cognitive testing, also called cognitive interviewing (Willis & Artino, 2013; Wharton et al., 1994; Lapka et al., 2008). The researcher asks participants to use the system while continuously thinking out loud as they move through the user interface (Nielsen, 2012). Thinking aloud questions include "Tell me what you are thinking," "What are you looking at?", or "What's on your mind?". The goal is for the users to make their thoughts transparent to the researcher. Verbal probing is another alternative for eliciting additional information about mHealth technology. It is a more active form of data collection in which the cognitive interviewer administers a series of probe questions specifically designed to elicit detailed information beyond that which is typically provided by respondents (Willis & Artino, 2013).

Another alternative to these approaches involves a postuse debrief where the interviewer observes the user going through the mHealth intervention, notes decisions made, and, after use, enquires about decisions made along each step of the way. The strength of this approach is that the user can go through the version naturally without disruption as a real user would. However, the downside is the risk that the user may forget what specific thoughts or motivations influenced their decisions during real-time use. Postuse debrief questions may include (1) whether the tool captured issues of importance to the user, (2) whether the tool was easy to use and understand regarding question wording and interface, and (3) whether there were other ways the system could be improved.

A different option involves the collection of observations to record information about behavior. This can be done in real time through the collection of notes while observing or through recordings of the user's interactions and using video elicitation interviews (Henry & Fetters, 2012). Video elicitation interviews question the user about their experiences and choices at certain points while interacting, for example, specific choices made and reasons for leaving a screen or returning to it. Tobii Pro can allow the researcher to track eye movements that convey behavioral patterns of use while interfacing with the mHealth technology.

Semistructured interviews and cognitive interviewing are suitable in the early stages of development. The goal is to identify bugs in the system, that is, anything that is dysfunctional or suboptimal. In later stages, verbal probing and video elicitation interviews are recommended to obtain specific data about the engineered changes.

### 6.2.3 Step 3: Integration in the Data Analysis Dimension

There are 2 approaches for an integrated analysis: an interactive analysis strategy or an independent intramethod analysis (Moseholm & Fetters, 2017).

#### *6.2.3.1 Interactive Analysis Strategy*

The interactive analysis strategy (Moseholm & Fetters, 2017), also called a crossover-tracks analysis (Teddlie & Tashakkori, 2009), means that the researcher considers the qualitative and quantitative findings, in real time, as the data are collected and analyzed. That is, the data are openly, actively, and interactively considered in the context of each other. Metaphorically, the data are talking to each other.

#### *6.2.3.2 Independent Intramethod Strategy*

The independent intramethod strategy, also called a parallel-tracks analysis (Teddlie & Tashakkori, 2009), means that the researcher uses an intramethod (ie, within method) qualitative data analysis strategy separately or independently to the quantitative data analysis strategy. First, each type of data is examined using a strategy appropriate for the type of data, for example, statistical analysis of quantitative data and thematic analysis of the qualitative data. After the separate/independent analysis, the findings are then integrated to draw an overarching interpretation, so-called metainferences in MMR methodology (Teddlie & Tashakkori, 2009).

For an iterative convergent design, the research can and likely will use both strategies depending on the stage of testing. The interactive analysis strategy is preferred, especially during early prototype testing when the number of users will invariably be smaller and there is an urgency for identifying major issues. As statistical analyses will not be feasible or necessary, this approach allows rapidly assessing user rankings of certain features, for example, using the SUS as well as their qualitative experiences with the system.

In later cycles of testing, the analysis may shift to a more independent intramethod analysis strategy. As a higher number of users engage and real-time automated digital user data emerge, the interactive analysis approach may become more challenging to conduct. Moreover, the independent intramethod analysis may be preferred when the scale of testing expands such that blinded quantitative data collection becomes more important. Doing so can enable the researcher to avoid validity threats to the data quality that could occur by changing the data collection approach or by sharing patterns with users in real time. For example, Kron et al. (2017) linked the qualitative findings from learners' reflections on their experiences after completing the qualitative and quantitative analyses.

#### *6.2.3.3 Combined Independent and Interactive Data Analysis*

The third option can involve an iteration of both interactive and independent data analyses, that is, user survey and interview data conducted in real time can be looked at interactively, whereas automated data collection that accumulates as the number of users expands may be brought into the results of the interactive analysis after being examined independently. The exact approach may vary and evolve according to development needs.

#### *6.2.3.4 The Fit of the Two Types of Data When Considered Together*

Comparing both the qualitative and quantitative findings allows researchers to examine the similarities, differences, or contradictions. This comparison also allows researchers to obtain an expanded understanding of when the qualitative and quantitative findings from the analyses are merged for an interpretation. Similarities occur when there is convergence or confirmation between the qualitative and quantitative findings. Differences occur when the 2 types of data illustrate different, nonconflicting interpretations, so-called complementarity (Greene et al., 1989). There is an expanded understanding, namely, expansion, when qualitative and quantitative finding provides a broader understanding of a central commonality (Fetters & Molina-Azorin, 2017; Fetters et al., 2013). Contradictions occur when there is discordance or divergence between the findings of the qualitative and quantitative data. To handle discordance, Fetters et al recommend gathering additional data, reanalyzing existing databases to resolve differences, seeking explanations from theory, or challenging the validity of the constructs (Fetters & Molina-Azorin, 2017; Fetters et al., 2013).

### 6.2.4 Step 4: Integration in the Data Interpretation Dimension

A key challenge in mixed methods studies is how to merge the qualitative and quantitative data. A very promising approach of growing popularity among mixed methods researchers is the creation of a joint display (Guetterman et al., 2015). Table 6.4 provides an example of presenting matched quantitative and qualitative data through a joint display. This joint display is derived from a randomized multisite mixed methods trial designed to compare a medical student's attitudes and experiences regarding the intervention, a virtual human-computer simulation program teaching communication skills, or a control, a computer-based learning module focused on teaching communication skills (Kron et al., 2017). The data collection for this project included usability-focused questioning .

**Table 6.4:** A joint display adapted from Kron et al's MPathic-VR mixed methods trial comparing a virtual human simulation and a computer-based communications module that illustrates medical students' attitudes and experiences in both trial arms.

| **Domains** | **MPathic-VR** | | **Computer Based Learning** | | **Interpretation of mixed methods findings** |
|---|---|---|---|---|---|
| | **Attitudinal item, mean (SD)** | **Qualitative reflection; illustrative quotes** | **Attitudinal item, mean (SD)** | **Qualitative reflection; illustrative quotes** | |
| Verbal communication | 5.02 (1.62) | "How to introduce myself without making assumptions about the cultural background of the patient and the family" | 3.89 (1.67) | "This educational module was useful for clarifying the use of SBAR and addressing ways that all members of a health care team can improve patient care through better communication skills" | Intervention arm comments suggest deeper understanding of the content than teaching using memorization and mnemonics as in the control, a difference confirmed by higher attitudinal scores |

| | | | | | |
|---|---|---|---|---|---|
| Nonverbal communication | 4.11 (1.85) | “Effective communication involves non-verbal facial expression like smiling and head nodding” | 2.77 (1.45) | None | Intervention arm comments address the value of learning nonverbal communication, the difference confirmed by attitudinal scores |
| Training was engaging | 5.43 (1.55) | “Reviewing the video review was a great way to see my facial expressions and it allowed me to improve on these skills the second time around” | 3.69 (1.62) | “This experience can be improved by incorporating more active participation. For example, there could have been a scenario in which we would have to select the appropriate hand-off information per SBAR guideline” | Intervention arm comments reflect engagement through the after-action review, whereas the control comments suggested the need for interaction, the difference confirmed by higher attitudinal scores |

| | | | | | |
|---|---|---|---|---|---|
| Effectiveness in learning to handle emotionally charged situations | 5.13 (1.48) | "I tend to try to smile more often than not in emotionally charged situations and that may result in conveying the wrong message" | 2.34 (1.35) | "I anticipate that high-stress situations where time is exceedingly crucial requires modification to the methods presented." | Intervention arm comments indicate awareness of communication in emotionally charged situations, yet control comments indicate the need for additional training, a difference confirmed in attitudinal scores |

Joint displays allow researchers to integrate data through visual means to draw out new insights beyond the information gained from the separate quantitative and qualitative results (Fetters et al., 2013; Guetterman et al., 2015). Joint displays are commonly built by organizing quantitative and qualitative findings of a related construct or topic in a table. When matching has been used during data collection, this process follows naturally. In the case of mHealth, the joint display might include the usability constructs, user's perceptions, and an image or even a video representing the task (Usability.gov, n.d.b). For example, SUS and ISO metrics can be used to populate the numerical score in the quantitative column. In addition, themes and representative quotations can be used to populate the qualitative column. In the final column, metainferences, an interpretation in consideration of the qualitative and quantitative findings, are made about the findings when analyzed together.

### 6.2.5 Step 5: Developer Updates the Mobile Health Intervention

After merging the data and drawing interpretations about their cumulative meaning (making metainferences), an iterative convergent mixed methods design then involves the results being communicated to the developers who will include the recommendations in the new iteration of the intervention. Moreover, as the developers make changes, they may also have specific questions to be answered in the subsequent cycle of iterative convergent data collection. Thus, newly emerging questions are added into subsequent rounds of data collection. In general, both qualitative and quantitative data (task completion rate, task completion time, number of errors, completing rate, and the SUS questionnaire) should be compared with each iteration for new mHealth versions.

### 6.2.6 Step 6: Iterative Evaluation

As illustrated in Figure 6.3, after 1 cycle of iterative evaluation, the next step is to develop a new version that has incorporated the findings from the previous evaluation. For example, Beatty et al. (2018) compared the task completion success rate and SUS across iterations of the mHealth intervention. The procedure will be similar by going back to Step 2: Integration in the Data Collection Dimension. With the new iteration, there will be new questions to ask, sometimes more general and sometimes more specific, depending on what changes were made. Furthermore, a new iteration is also required when the researcher introduces a new feature or functionality to the mHealth intervention.

On the basis of the results of the usability test, many changes may be required. The researcher should prioritize these changes while focusing on the user's needs. Generally, the magnitude of data collection and intensity will change. In the early rounds of development, the qualitative component of the mixed methods evaluation will weigh more heavily for identifying the macrolevel changes (Figure 6.2). This is more of a qualitatively driven mixed methods approach (Moseholm & Fetters, 2017). In subsequent iterations, as the prototype moves from paper to digital prototype to product, changes may depend much more heavily on the quantitative automated analyses that can accumulate with increased numbers of users, a quantitatively driven approach. Hence, in later cycles, the quantitative data may help identify problems, whereas the qualitative data can be used to identify solutions.

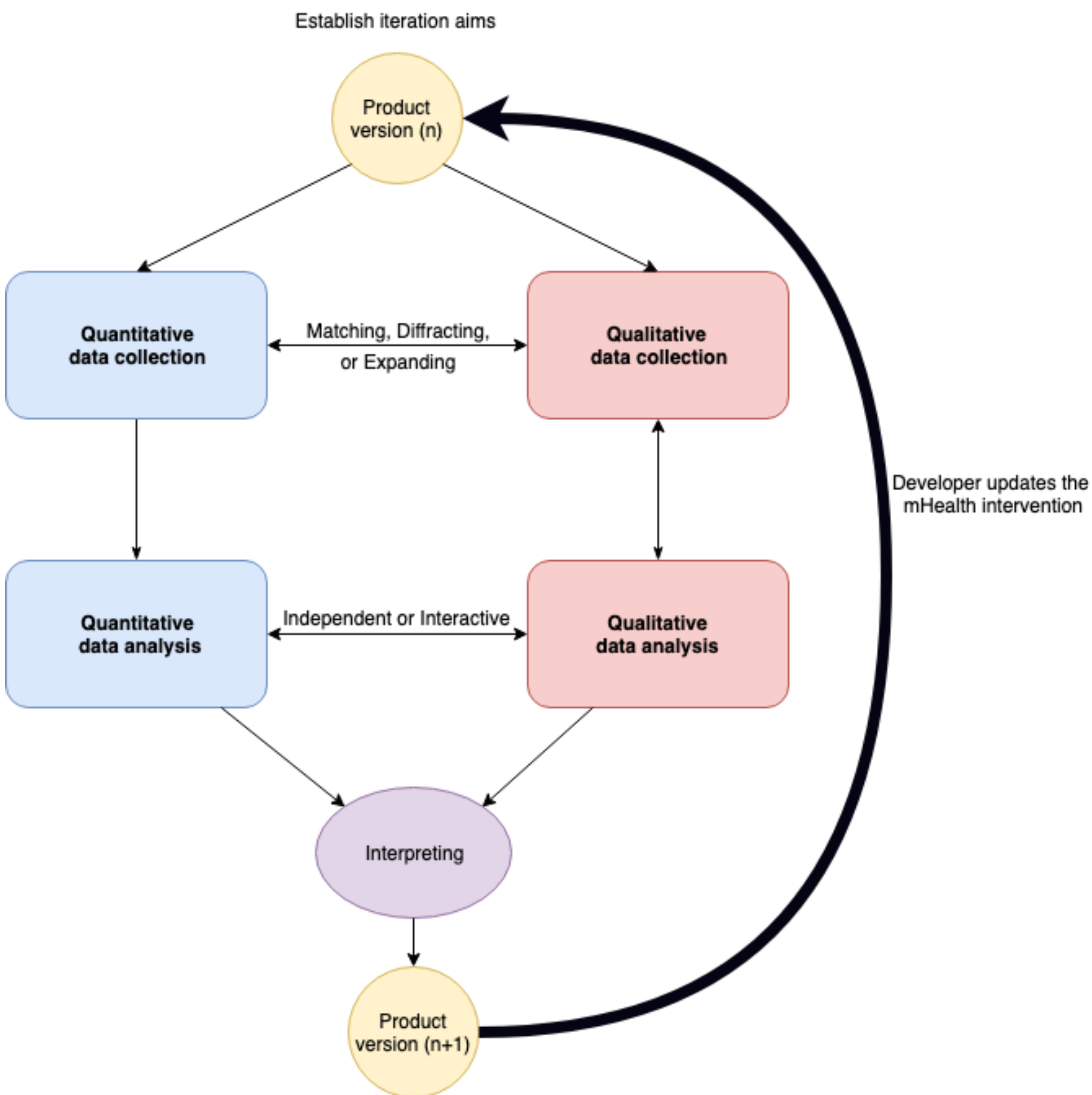



**Figure 6.3:** The iterative convergent mixed methods research design.

### 6.2.7 Reaching Closure in an Iterative Convergent Mixed Methods Design

Many researchers use the concept of saturation when conducting usability testing (Press et al., 2015; Voncken-Brewster et al., 2013). Saturation represents the point at which the researcher stops collecting data based on the criterion of not finding new information relevant to the development of the mHealth application. Researchers also have the option for longitudinal evaluation by comparing user satisfaction with the new mHealth technology with the result of the

SUS across iterations. Similarly, qualitative data about specific features can be compared as well. After usability testing, the final prototype of the mHealth intervention can then be included in a pilot study for final refinement before launching it in a larger trial. During these subsequent phases, the iterative convergent mixed methods design will naturally continue, even into the trial.

## 6.3 Discussion

Here, we emphasize the need and process for mHealth researchers to use state-of-the-art mixed methods procedures. Previous single method usability studies were limited in their findings. Some studies have assessed usability using only qualitative data(Lodhia et al., 2016; Wang et al., 2018; Khurana et al., 2016). These studies can only elucidate an understanding of how and why participants make certain choices when using a prototype or their overall assessment of the utility. On the contrary, some studies have used quantitative data exclusively to assess usability (Schobel et al., 2018; Metelmann et al., 2018). These studies are limited to specific questions about usability and could miss valuable experiential information.

### 6.3.1 Features of the Iterative Convergent Mixed Methods Design

Despite the recognized value of using mixed methods for usability testing (Alnasser et al., 2018; Beatty et al., 2018; and Sage et al., 2017; Andargoli et al., 2017), researchers have lacked a specific design and clear procedures featuring an integrated approach that is focused on mHealth development. We believe, and the identified literature supports, that many researchers in the field are only using qualitative and quantitative procedures separately without a focus on the features of integration (Beatty et al., 2018; Alnasser et al., 2018; Farinango et al., 2018). This illustrates explicitly why mHealth intervention researchers need a better understanding of how to incorporate the latest advances in MMR methodology, which explicitly emphasizes integration, and has procedures for achieving it.

We suggest the following criteria for evaluating the quality of studies that have used the iterative convergent mixed methods design:

1. The authors report on an empirical mHealth-related usability study.
2. The authors use an integrated mixed methods approach, defined as the collection, analysis, and integration of quantitative and qualitative data (Creswell & Clark, 2018).
3. The authors compare the results of various iterations of the mHealth intervention.

The iterative convergent mixed methods design provides a clear framework for integrating quantitative and qualitative data to assess usability. As illustrated in Figure 6.3, there are multiple dimensions during testing, questions, data collection, analysis, and interpretation as well as subsequent data collection that characterize an iterative convergent mixed methods design.

With this design, researchers will start with a mockup, prototype, or the actual mHealth intervention that is represented in the diagram by the circle named the mHealth technology version. In each round, the researcher will evaluate aspects of the version using both qualitative and quantitative research aims and, importantly, making overarching interpretations or metainferences based on the findings of both types of data that inform the next steps (Teddlie & Tashakkori, 2009). During data collection, the researcher can use matching, diffracting, or expanding as data are collected. Employing specific data collection approaches, the constructs explored quantitatively with scales can be explored with a similar line of qualitative questioning or inquiry. Once the data are brought together, they are compared so as to examine their confirmation, expansion, differing interpretations, or discordance (Fetters et al., 2013). As successive versions of the mHealth technology are produced, each version will involve both qualitative and quantitative data collection brought together for an integrated analysis. Iterative qualitative and quantitative data collection can be compared with each iteration to create the most usable version of the mHealth technology.

### 6.3.2 Limitations

There are potential limitations to the current usability approach. Although the small sample size may resolve the majority of usability issues (Nielsen, 2018), usability testing with a small number of individuals will generally reveal major flaws or bugs in the system. As the mHealth intervention becomes refined and moves from the protocol stage to the actual use stage, access to quantitative data rapidly increases and becomes more of a focus.

Usability testing can be conducted on the Web or in a laboratory setting. The value of Web-based testing is that users can participate from their natural context and use their own devices. It is also more cost-effective, and users can be in any location with an internet connection. In a laboratory setting, the researcher can probe users while they walk through their tasks, gather visual cues, assist stumped users, and ask new questions during the testing session.

We acknowledge that there are other methods, including other mixed methods designs (Fetters et al., 2013), potentially applicable for usability and design research, for example, mixed methods interventions or trials. There are also other scales that can be used to quantify the satisfaction construct, such as the Post Study System Usability Questionnaire (Lewis, 1992). Addressing all of these methods and scales extends beyond the scope of our current focus.

## 6.4 Conclusions

A usable mHealth intervention with high user satisfaction can have a significantly positive effect on mHealth adoption, resulting in improved health outcomes and quality of life and reduced overall health care costs. Effective mHealth interventions are critically important for empowering patients to manage their health and also potentially enable them to participate more actively in shared decision making with their health care providers. This study offers a novel framework to guide mHealth research that has the potential to generate unique insights into multifaceted phenomena related to usability. Understanding these practices can help developers and researchers leverage the strengths of an integrated mixed methods design.

## 6.6 References


Alwashmi, M., Hawboldt, J., Davis, E., Marra, C., Gamble, J. M., & Ashour, W. A. (2016). The effect of smartphone interventions on patients with chronic obstructive pulmonary disease exacerbations: a systematic review and meta-analysis. JMIR mHealth and uHealth, 4(3), e105.

Alnasser, A., Kyle, J., Alkhalifah, A., & Marais, D. (2018). Relationship between evidence requirements, user expectations, and actual experiences: usability evaluation of the Twazon Arabic weight loss app. JMIR human factors, 5(2), e16.

Andargoli, A. E., Scheepers, H., Rajendran, D., & Sohal, A. (2017). Health information systems evaluation frameworks: A systematic review. International journal of medical informatics, 97, 195-209.

Aranda-Jan, C. B., Mohutsiwa-Dibe, N., & Loukanova, S. (2014). Systematic review on what works, what does not work and why of implementation of mobile health (mHealth) projects in Africa. BMC public health, 14(1), 188.

Beatty, A. L., Magnusson, S. L., Fortney, J. C., Sayre, G. G., & Whooley, M. A. (2018). VA FitHeart, a mobile app for cardiac rehabilitation: usability study. JMIR human factors, 5(1), e3.

Bevan, N., Carter, J., & Harker, S. (2015, August). ISO 9241-11 revised: What have we learnt about usability since 1998?. In International Conference on Human-Computer Interaction (pp. 143-151). Springer, Cham.

Brooke, J. (1996). SUS-A quick and dirty usability scale. Usability evaluation in industry, 189(194), 4-7.

Carayon, P., Kianfar, S., Li, Y., Xie, A., Alyousef, B., & Wooldridge, A. (2015). A systematic review of mixed methods research on human factors and ergonomics in health care. Applied ergonomics, 51, 291-321.

Creswell, J. W., & Clark, V. L. P. (2018). Designing and conducting mixed methods research. Sage publications.

Creswell, J. W., Klassen, A. C., Plano Clark, V. L., & Smith, K. C. (2011). Best practices for mixed methods research in the health sciences. Bethesda (Maryland): National Institutes of Health, 2013, 541-545.

Creswell, J. W., Plano Clark, V. L., Gutmann, M. L., & Hanson, W. E. (2003). Advanced mixed methods research designs. Handbook of mixed methods in social and behavioral research, 209, 240.

Creswell, J. W. (2015). A concise introduction to mixed methods research. SAGE publications.

Curry, L., & Nunez-Smith, M. (2015). Assessing Quality in Mixed Methods Studies. Mixed Methods in Health Sciences Research: A Practical Primer, 169-200.

Curry, L. A., Nembhard, I. M., & Bradley, E. H. (2009). Qualitative and mixed methods provide unique contributions to outcomes research. Circulation, 119(10), 1442-1452.

Dorsey, E. R., McConnell, M. V., Shaw, S. Y., Trister, A. D., & Friend, S. H. (2017). The use of smartphones for health research. Academic Medicine, 92(2), 157-160.

Farinango, C. D., Benavides, J. S., Cerón, J. D., López, D. M., & Álvarez, R. E. (2018). Human-centered design of a personal health record system for metabolic syndrome management based on the ISO 9241-210: 2010 standard. Journal of multidisciplinary healthcare, 11, 21.

Fetters, M. D., & Freshwater, D. (2015). The 1+ 1= 3 Integration Challenge.

Fetters, M. D., & Molina-Azorin, J. F. (2017). The journal of mixed methods research starts a new decade: principles for bringing in the new and divesting of the old language of the field.

Fetters, M. D., Curry, L. A., & Creswell, J. W. (2013). Achieving integration in mixed methods designs—principles and practices. Health services research, 48(6pt2), 2134-2156.

Fetters, M. D. (2018). Six equations to help conceptualize the field of mixed methods.

Fogel, A. L., & Kvedar, J. C. (2018). Artificial intelligence powers digital medicine. NPJ digital medicine, 1(1), 5.

Georgsson, M., & Staggers, N. (2015). Quantifying usability: an evaluation of a diabetes mHealth system on effectiveness, efficiency, and satisfaction metrics with associated user characteristics. Journal of the American Medical Informatics Association, 23(1), 5-11.

Goldberg, L., Lide, B., Lowry, S., Massett, H. A., O'Connell, T., Preece, J., ... & Shneiderman, B. (2011). Usability and accessibility in consumer health informatics: current trends and future challenges. American journal of preventive medicine, 40(5), S187-S197.

Gray, C. S., Khan, A. I., Kuluski, K., McKillop, I., Sharpe, S., Bierman, A. S., ... & Cott, C. (2016). Improving patient experience and primary care quality for patients with complex chronic disease using the electronic patient-reported outcomes tool: adopting qualitative methods into a user-centered design approach. JMIR research protocols, 5(1), e28.

Greene, J. C., Caracelli, V. J., & Graham, W. F. (1989). Toward a conceptual framework for mixed-method evaluation designs. Educational evaluation and policy analysis, 11(3), 255-274.

Guetterman, T. C., Fetters, M. D., & Creswell, J. W. (2015). Integrating quantitative and qualitative results in health science mixed methods research through joint displays. The Annals of Family Medicine, 13(6), 554-561.

Gunter, R., Fernandes-Taylor, S., Mahnke, A., Awoyinka, L., Schroeder, C., Wiseman, J., ... & Kent, K. C. (2016). Evaluating patient usability of an image-based mobile health platform for postoperative wound monitoring. JMIR mHealth and uHealth, 4(3), e113.

Hattink, B., Droes, R. M., Sikkes, S., Oostra, E., & Lemstra, A. W. (2016). Evaluation of the Digital Alzheimer Center: testing usability and usefulness of an online portal for patients with dementia and their carers. JMIR research protocols, 5(3), e144.

Hayes, D. F., Markus, H. S., Leslie, R. D., & Topol, E. J. (2014). Personalized medicine: risk prediction, targeted therapies and mobile health technology. BMC medicine, 12(1), 37.

Henry, S. G., & Fetters, M. D. (2012). Video elicitation interviews: a qualitative research method for investigating physician-patient interactions. The Annals of Family Medicine, 10(2), 118-125.

Hesse-Biber, S. N., & Johnson, R. B. (Eds.). (2015). The Oxford handbook of multimethod and mixed methods research inquiry. Oxford University Press.

Hopkins, I. G., Dunn, K., Bourgeois, F., Rogers, J., & Chiang, V. W. (2016, June). From development to implementation—A smartphone and email-based discharge follow-up program for pediatric patients after hospital discharge. In Healthcare(Vol. 4, No. 2, pp. 109-115). Elsevier.

Horton, K. (2008). The use of telecare for people with chronic obstructive pulmonary disease: implications for management. Journal of nursing management, 16(2), 173-180.

International Organization for Standardization. (2018). Ergonomics of human-system interaction - part 11: Usability: Definitions and concepts

ISO, E. (2010). 9241-210: Ergonomics of human-system interaction. Human-centred design for interactive systems.

Joe, J., & Demiris, G. (2013). Older adults and mobile phones for health: a review. Journal of biomedical informatics, 46(5), 947-954.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. Journal of mixed methods research, 1(2), 112-133.

Juen, J., Cheng, Q., & Schatz, B. (2015). A natural walking monitor for pulmonary patients using mobile phones. IEEE Journal of biomedical and health informatics, 19(4), 1399-1405.

Källander, K., Tibenderana, J. K., Akpogheneta, O. J., Strachan, D. L., Hill, Z., ten Asbroek, A. H., ... & Meek, S. R. (2013). Mobile health (mHealth) approaches and lessons for increased performance and retention of community health workers in low-and middle-income countries: a review. Journal of medical Internet research, 15(1), e17.

Khurana, L., Durand, E. M., Gary, S. T., Otero, A. V., Gerzon, M. C., Beck, J., ... & Dallabrida, S. M. (2016). Subjects with osteoarthritis can easily use a handheld touch screen electronic device to report medication use: qualitative results from a usability study. Patient preference and adherence, 10, 2171.

Kron, F. W., Fetters, M. D., Scerbo, M. W., White, C. B., Lypson, M. L., Padilla, M. A., ... & Guetterman, T. C. (2017). Using a computer simulation for teaching communication skills: A blinded multisite mixed methods randomized controlled trial. Patient education and counseling, 100(4), 748-759.

Krug, Steve author. (2014). Don't make me think, revisited : a common sense approach to Web usability. [Berkeley, Calif.] :New Riders,

Lapka, C., Jupka, K., Wray, R. J., & Jacobsen, H. (2008). Applying cognitive response testing in message development and pre-testing. Health education research, 23(3), 467-476.

Lewis, J. R. (1992, October). Psychometric evaluation of the post-study system usability questionnaire: The PSSUQ. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 36, No. 16, pp. 1259-1260). Sage CA: Los Angeles, CA: SAGE Publications.

Lodhia, V., Karanja, S., Lees, S., & Bastawrous, A. (2016). Acceptability, usability, and views on deployment of Peek, a mobile phone mHealth intervention for eye care in Kenya: qualitative study. JMIR mHealth and uHealth, 4(2), e30.

Lyles, C. R., Sarkar, U., & Osborn, C. Y. (2014). Getting a technology-based diabetes intervention ready for prime time: a review of usability testing studies. Current diabetes reports, 14(10), 534.

Mayberry, L. S., Mulvaney, S. A., Johnson, K. B., & Osborn, C. Y. (2017). The MEssaging for Diabetes intervention reduced barriers to medication adherence among low-income, diverse adults with type 2. Journal of diabetes science and technology, 11(1), 92-99.

Mertens, D. M. (2014). Mixed methods and wicked problems.

Metelmann, B., Metelmann, C., Schuffert, L., Hahnenkamp, K., & Brinkrolf, P. (2018). Medical correctness and user friendliness of available apps for cardiopulmonary resuscitation: systematic search combined with guideline adherence and usability evaluation. JMIR mHealth and uHealth, 6(11), e190.

Moseholm, E., & Fetters, M. D. (2017). Conceptual models to guide integration during analysis in convergent mixed methods studies. Methodological Innovations, 10(2), 2059799117703118.

Moumane, K., Idri, A., & Abran, A. (2016). Usability evaluation of mobile applications using ISO 9241 and ISO 25062 standards. SpringerPlus, 5(1), 548.

Nelson, L. A., Mayberry, L. S., Wallston, K., Kripalani, S., Bergner, E. M., & Osborn, C. Y. (2016). Development and usability of REACH: a tailored theory-based text messaging intervention for disadvantaged adults with type 2 diabetes. JMIR human factors, 3(2), e23.

Nielsen, J. (2012). Thinking aloud: The# 1 usability tool. Nielsen Norman Group [online]. January, 16.

Nielsen, J. (2018). How many test users in a usability study.. Nielsen Norman Group. Retrieved from: URL: https://www.nngroup.com/articles/how-many-test-users/

Nitsch, M., Dimopoulos, C. N., Flaschberger, E., Saffran, K., Kruger, J. F., Garlock, L., ... & Jones, M. (2016). A guided online and mobile self-help program for individuals with eating disorders: An iterative engagement and usability study. Journal of medical Internet research, 18(1), e7.

Press, A., McCullagh, L., Khan, S., Schachter, A., Pardo, S., & McGinn, T. (2015). Usability testing of a complex clinical decision support tool in the emergency department: lessons learned. JMIR human factors, 2(2), e14.

Research2guidance. (2018). mHealth economics - how mHealth app publishers are monetizing their apps. Retrieved from URL: https://research2guidance.com/product/mHealth-economics-how-mHealth-app-publishers-are-monetizing-their-apps/

Ribeiro, N., Moreira, L., Barros, A., Almeida, A. M., & Santos-Silva, F. (2016). Guidelines for a cancer prevention smartphone application: a mixed-methods study. International journal of medical informatics, 94, 134-142.

Sage, A., Roberts, C., Geryk, L., Sleath, B., Tate, D., & Carpenter, D. (2017). A Self-Regulation Theory–Based Asthma Management Mobile App for Adolescents: A Usability Assessment. JMIR human factors, 4(1), e5.

Sarkar, U., Gourley, G. I., Lyles, C. R., Tieu, L., Clarity, C., Newmark, L., ... & Bates, D. W. (2016). Usability of commercially available mobile applications for diverse patients. Journal of general internal medicine, 31(12), 1417-1426.

Schobel, J., Pryss, R., Probst, T., Schlee, W., Schickler, M., & Reichert, M. (2018). Learnability of a configurator empowering end users to create mobile data collection instruments: Usability study. JMIR mHealth and uHealth, 6(6), e148.

Smith, S. A., Claridy, M. D., Whitehead, M. S., Sheats, J. Q., Yoo, W., Alema-Mensah, E. A., ... & Coughlin, S. S. (2015). Lifestyle modification experiences of African American breast cancer survivors: a needs assessment. JMIR cancer, 1(2), e9.

Tashakkori, A., Teddlie, C., & Teddlie, C. B. (1998). Mixed methodology: Combining qualitative and quantitative approaches (Vol. 46). Sage.

Teddlie, C., & Tashakkori, A. (2009). Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences. Sage.

Teherani, A., Martimianakis, T., Stenfors-Hayes, T., Wadhwa, A., & Varpio, L. (2015). Choosing a qualitative research approach. Journal of graduate medical education, 7(4), 669-670.

Triantafyllidis, A., Velardo, C., Chantler, T., Shah, S. A., Paton, C., Khorshidi, R., ... & SUPPORT-HF Investigators. (2015). A personalised mobile-based home monitoring system for heart failure: the SUPPORT-HF Study. International journal of medical informatics, 84(10), 743-753.

Uprichard, E., & Dawney, L. (2019). Data diffraction: Challenging data integration in mixed methods research. Journal of Mixed Methods Research, 13(1), 19-32.

Usability.gov a. Benefits of user-centered design. Retrieved from URL: https://www.usability.gov/what-and-why/benefits-of-ucd.html

Usability.gov b. Reporting usability test results. Retrieved from URL: https://www.usability.gov/how-to-and-tools/methods/reporting-usability-test-results.html

Vashist, S. K., Luppa, P. B., Yeo, L. Y., Ozcan, A., & Luong, J. H. (2015). Emerging technologies for next-generation point-of-care testing. Trends in biotechnology, 33(11), 692-705.

Voncken-Brewster, V., Moser, A., van der Weijden, T., Nagykaldi, Z., de Vries, H., & Tange, H. (2013). Usability evaluation of an online, tailored self-management intervention for chronic obstructive pulmonary disease patients incorporating behavior change techniques. JMIR research protocols, 2(1), e3.

Wang, J., Chu, C. F., Li, C., Hayes, L., & Siminerio, L. (2018). Diabetes educators' insights regarding connecting mobile phone–and wearable tracker–collected self-monitoring information to a nationally-used electronic health record system for diabetes education: Descriptive qualitative study. JMIR mHealth and uHealth, 6(7), e10206.

Watson H. IBM. Watson Health: Get the Facts. Retrieved from URL: https://www.ibm.com/blogs/watson-health/watson-health-get-facts/

Wharton, C. (1994). The cognitive walkthrough method: A practitioner's guide. Usability inspection methods.

Willis, G. B., & Artino Jr, A. R. (2013). What do our respondents think we're asking? Using cognitive interviewing to improve medical education surveys. Journal of graduate medical education, 5(3), 353-356.

World Health Organization. (2011). mHealth: new horizons for health through mobile technologies. mHealth: new horizons for health through mobile technologies.

Zapata, B. C., Fernández-Alemán, J. L., Idri, A., & Toval, A. (2015). Empirical studies on usability of mHealth apps: a systematic literature review. Journal of medical systems, 39(2), 1.

Zhang, J., Song, Y. L., & Bai, C. X. (2013). MIOTIC study: a prospective, multicenter, randomized study to evaluate the long-term efficacy of mobile phone-based Internet of Things in the management of patients with stable COPD. International journal of chronic obstructive pulmonary disease, 8, 433.

# Chapter 7: Summary

This chapter briefly summarizes the research and the findings. The implications of the research are then discussed, followed by recommendations for further research on developing mHealth interventions for COPD management.

## 7.1 General Discussion

The main goal of this program of research is to investigate how to apply the Human-Centered Design process when developing an mHealth intervention for COPD management. A set of research questions was designed to facilitate this research. To examine this process, we produced five unique journal articles: 1) a systematic review and meta-analysis of the effect of mHealth interventions on exacerbations for patients with COPD; 2) a qualitative study to explore the perceptions of healthcare providers regarding an mHealth intervention for COPD management; 3) a mixed methods study to explore the perceptions of patients with COPD regarding an mHealth intervention for COPD management; 4) a qualitative study to identify the features of an mHealth intervention for COPD management; and 5) developing a mixed methods approach, the iterative convergent design, for mHealth usability testing.

The first study (chapter 2) was conducted to determine if mHealth can be effective in reducing COPD exacerbations. It elaborated on how I answered the following research question: "Based on the existing literature, what is the association between mHealth interventions and the management of COPD exacerbations?" A systematic review and meta-analysis were performed to summarize and quantify the association between mHealth interventions and the management of COPD exacerbations.

Although the current literature on the role of mHealth in reducing COPD exacerbations is limited, findings from my review suggest that mHealth interventions are potentially useful in reducing the number of patients with a COPD exacerbation. Of the 245 unique citations screened, six studies were included in the qualitative synthesis. The qualitative synthesis included data regarding the study design, study procedure, intervention, population demographics, and number of patients having an exacerbation. All the articles were published after 2008. All of the studies were conducted on relatively small samples, less than 100 participants each. The pooled random-effects odds ratio of patients having an exacerbation was 0.20 in patients using a smartphone intervention (95% CI 0.07-0.62), a reduction of 80% for smartphone interventions compared with usual care. However, there was moderate heterogeneity across the included studies ($I^2$=59%). These results should be interpreted with caution due to the heterogeneity among the studies. Another recommendation that emerged from the systematic review was the need for implementing a mixed methods research design to investigate the validity and clinical utility of smartphone interventions that could help to understand why a particular component is successful and how patients will use mHealth interventions for in the long term.

My second study (chapter 3) examined some of the perceived barriers and facilitators of adopting an mHealth intervention to manage COPD, according to HCPs. This study was conducted to answer the following research question: What are the potential facilitators and barriers that might influence healthcare providers of patients with COPD regarding the use of mHealth in COPD management? To answer this, I developed a qualitative study. A total of 30 nurses, physicians, and pharmacists participated. The main facilitators to mHealth adoption are possible health benefits for patients, ease of use, educating patients and their HCPs, credibility, and reducing the cost to the health care system. Alternatively, the barriers to adoption are technical issues, privacy and confidentiality issues, lack of awareness, potential limited uptake from the elderly, potential limited connection between patients and HCPs, and finances. These facilitators and barriers may inform the successful development and implementation of mHealth interventions for COPD management.

The third study (chapter 4) explored the perceptions of patients with COPD regarding the use of mHealth in COPD management. This resulted in the following research questions: What are the potential facilitators and barriers that might influence patients with COPD regarding the use of mHealth in COPD management? What are the demographics, use, and access to smartphones among patients with COPD? I developed an explanatory sequential mixed methods study to answer these questions.

Patients with COPD completed a survey to assess how they use various types of mobile technology and to what extent they use mHealth. The quantitative component revealed that many COPD patients owned a mobile phone, but only about a quarter of the participants, 18/77 (23.4%), owned a smartphone. The likelihood of owning a smartphone was not associated with age, sex, marital status, or geographical location, but patients with high educational status were more likely to own a smartphone. I collected qualitative data through interviews to further explicate the data collected from the surveys and provide a richer depiction of the data. The qualitative component found that COPD patients, in general, had a positive attitude toward mHealth adoption for COPD management, but several facilitators and barriers were identified. It is important to promote the facilitators and address the barriers to optimize the successful implementation of mHealth interventions.

In comparison with the facilitators reported by HCPs, patients had four parallel facilitators: there are possible health benefits for patients, the software needs to be easy to use, patients need to be educated on the use of mHealth, and the credibility of mHealth should be evident (Alwashmi et al., 2019a). The only facilitator that was not mentioned by patients is that mHealth should reduce the cost to the healthcare system. On the other hand, patients had five parallel barriers with the HCPs: there are technical issues with mHealth, lack of awareness is a challenge, there may be limited uptake from the elderly, there are possible financial barriers, and there may be privacy and confidentiality concerns (Alwashmi et al., 2019a). The possibility of mHealth limiting the personal connection between HCPs and patients was not mentioned as a barrier by patients. Furthermore, one new barrier emerged from interviewing patients: some patients were not interested in using mHealth interventions. Our findings, and the limited literature on the matter, emphasize the need for further research into the use of mHealth in COPD management.

In the fourth study (chapter 5), I focused on the features of the mHealth intervention. This resulted in the following research question: How can an mHealth intervention for COPD management be developed that takes into account the needs and requirements of patients with COPD and their HCPs? A list of recommendations was made based on interviews with patients with COPD and their HCPs. The recommendations provide a set of considerations for delivering an mHealth intervention to assist in the management of COPD. This collaborative and human-centered approach requires two different interfaces: one for patients and the other for HCPs. The mHealth intervention could potentially enhance COPD management using several features; most importantly, by collecting relevant subjective and objective data, then using it to tailor COPD management based on the patient's unique needs.

In the last article (chapter 6), a mixed methods framework, called the iterative convergent design, for usability testing is described. This framework was developed in response to a barrier that was identified by the majority of patients and HCPs — having difficulty in using the mHealth intervention. The following research question was addressed: What is the most suitable MMR framework for generating unique insights into the usability of mHealth? This usability framework is a relevant way of determining usability and patient perceptions toward an mHealth intervention. The iterative convergent mixed methods design provides a clear framework for integrating quantitative and qualitative data to assess usability, which is critical to the success of an mHealth intervention.

## 7.2 Applying human-centered design activity phases to mHealth development

This thesis follows the ISO HCD activity phases discussed in section 1.1.2.1. Figure 1.4 highlights the HCD and its associated thesis chapter. The first phase, understand and specify the context of use, was addressed in chapters 2–4. It consisted of identifying the user characteristics of both patients with COPD and their HCPs. Based on what we learned about how patients may use mHealth in COPD management, we were able to determine the usage requirements, which brings us to phase two.

The second phase consists of specifying the user requirements and defining those requirements for the system, based on what the user needs to do within the context of use. This phase was addressed in chapter 5. It includes the features and requirements for users, both patients and HCPs. In phase two, actions a user should be able to perform while interacting with the interface were described.

The third phase consists of producing design solutions to meet user requirements. Some design considerations were included in chapter 5. Ideally, a low-fidelity prototype would be developed after a few iterations that can be used for testing in the following phase.

In the final phase, the developed prototype can be used to evaluate the design solution from the user's perspective via usability testing. A meta-inference I observed from interviewing patients and HCPs was the importance of a usable mHealth intervention that could enhance mHealth adoption. Chapter 6 includes a mixed methods framework specifically for mHealth usability testing. Both quantitative and qualitative data are vital to understanding the user's needs and goals. MMR can capitalize on the strengths of both methods: the depth of qualitative research and the breadth of quantitative research. The resulting mixed data can be integrated to provide a more comprehensive understanding of a complex phenomenon, such as usability. After producing a usable mHealth intervention, the final version can be used in a pilot study, then a randomized controlled trial should be carried out to assess its effectiveness.

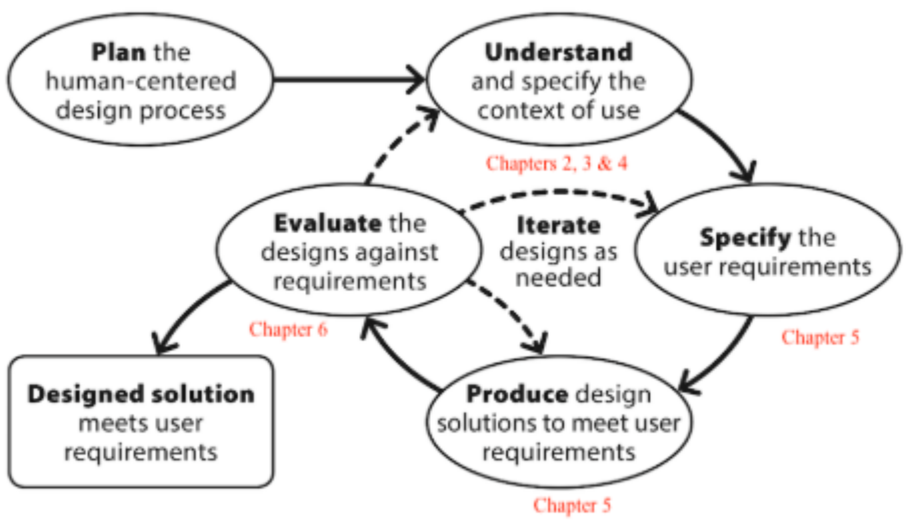



Figure 1.4 **Human-centered design activity phases and the associated thesis chapters.**

## 7.3 Study implications

Globally, we are seeing a push towards more patient-centered care. mHealth interventions have the potential to empower patients to manage their own health and also potentially enable them to participate more actively in shared decision making with their health care providers to optimize their COPD control and medication adherence. Given that COPD management is critical to positive health outcomes, a usable mHealth intervention with high user satisfaction and retention could have a significantly positive effect on health outcomes, quality of life, and reduced overall health care costs. The final, fully customized mHealth intervention will help to direct a future full-scale, randomized efficacy study to quantify these benefits.

There were a few barriers identified by the patients and their HCPs. Most of these barriers have the potential to be resolved, as suggested by many of the participants. This program of research highlights the barriers to adoption that can be addressed by various stakeholders. Additionally, some of these barriers and facilitators to mHealth adoption can be generalized to other chronic diseases, such as asthma, heart failure, and diabetes.

## 7.4 Areas for future research

The use of mHealth to manage COPD is still an emerging field of research. Experts in the field continue to identify areas in need of more research, clarification or guidance. My research program, as described in this dissertation, has further identified several questions. These are grouped according to the study in which they were identified, and broader questions are listed at the end.

I acknowledge that there are other frameworks potentially applicable for usability and design research, for example, Technology Acceptance Model (Davis et al., 1989) and Instructional Design (Reiser & Dempsey, 2012). There are also other theories that can be used to affect behaviour change, such as the self-efficacy theory (Bandura et al., 1977) and self-determination theory (Deci & Ryan, 2012). Addressing all of these methods and scales extends beyond the scope of our current focus.

### 7.4.1 Systematic review and meta-analysis of the effect of mHealth interventions on patients with COPD

Although the studies in this review have a small sample size and a relatively short follow-up period, current literature supports the potential of smartphones in reducing COPD exacerbations. There is a need for more studies that evaluate mHealth interventions, including studies that use smartphones as the main intervention. This will assist in determining whether smartphones can be effective in the management of COPD. Another systematic review was published last year with similar findings (Yang et al., 2018). They concluded that mHealth may help to reduce hospital admissions or improve the health status of patients with COPD. Future studies should include participants with different stages of COPD severity and age spans to minimize the risk of bias and enhance the generalizability of the study results.

### 7.4.2 Perceptions of healthcare providers regarding a Mobile Health intervention for COPD management

More research needs to be conducted to explore the perceptions of HCPs regarding the use of mHealth in COPD management. This includes conducting focus groups with some of the participants following individual interviews. Additionally, including the perspectives of allied HCPs, such as physiotherapists, social workers, and occupational therapists, would be beneficial to understand the perspectives of administrators (e.g., information technology managers) who may be able to identify some of the challenges with using mHealth for COPD management.

### 7.4.3 Perceptions of patients with COPD regarding a Mobile Health intervention for COPD management

As highlighted above, more research needs to be done to explore the perceptions of patients regarding the use of mHealth in COPD management. This includes conducting focus groups with some of the participants following individual interviews. We recruited patients who attended respirology clinics. Replicating the study with patients in a community setting or using digital recruitment methods (e.g. social media) could lead to different results, especially regarding the access to and use of mHealth.

### 7.4.4 Features of a Mobile Health intervention for COPD management

Similar to the previous studies, some recommendations include the use of a focus group, including the perspectives of allied HCPs and administrators, and obtaining perspectives from patients in a community setting.

### 7.4.5 The Iterative Convergent Design for Mobile Health Usability Testing: Mixed Methods Approach

This approach is geared towards enhancing the usability of mHealth interventions. Future studies could adopt this framework to potentially improve the effectiveness, efficiency and satisfaction of an mHealth intervention.

### 7.4.6 General areas for future research

While I have discussed recommendations for future research that were specific to each study, there are overarching goals that need to be addressed by future studies. This research makes contributions to the development of an mHealth intervention to manage COPD. However, the following points can be further improved in the future: 1) if further research is undertaken, the mHealth intervention should be developed fully; 2) usability testing should be conducted using the framework described in chapter 6; 3) additional trials will be required to provide data regarding the efficacy and cost-effectiveness of mHealth interventions in COPD management; and 4) a mixed methods framework could be developed to guide the process of producing design solutions of an mHealth intervention. It is also important to develop a framework that considers the introduction of new features, or medical devices, during the assessment of the mHealth intervention trial.

## 7. 5 Conclusion

This program of research used diverse research methods, including quantitative, qualitative, and mixed methods studies to examine the process of developing mHealth to manage COPD. These studies resulted in information about the effectiveness of COPD on reducing exacerbations, though as discussed, these findings were small in magnitude and may not be of clinical importance. More importantly, this research identifies several facilitators and barriers to mHealth adoption for COPD management. It also includes features of the mHealth intervention for both patients and HCPs. The last study provides methodological guidance to successfully perform usability testing for mHealth interventions. This is a developing field of research and a promising one for understanding how to use contemporary technologies in chronic disease management.

## 7.6 References


Bandura, A., & Adams, N. E. (1977). Analysis of self-efficacy theory of behavioral change. *Cognitive therapy and research*, *1*(4), 287-310.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, 319-340.

Deci, E. L., & Ryan, R. M. (2012). Self-determination theory.

Reiser, R. A., & Dempsey, J. V. (Eds.). (2012). *Trends and issues in instructional design and technology*. Boston, MA: Pearson.

Yang, F., Wang, Y., Yang, C., Hu, H., & Xiong, Z. (2018). Mobile health applications in self-management of patients with chronic obstructive pulmonary disease: a systematic review and meta-analysis of their efficacy. BMC pulmonary medicine, 18(1), 147.

# Appendix 1- HCP Interview prompts

## A- Health Care Providers

- Date and place
- Age and experience from general practice
- Job title

**General perceptions**

- Tell me a little bit about your experience with patients with COPD.
- What are the likely treatment outcomes?
- Do you know what mHealth is?

**Facilitators**

- Have you used mHealth before? (if no, go to barriers).
- Tell me about a situation when you have tried to use mHealth in your practice.
    - Why this episode?
    - What did you use it for?
    - What data did you collect?
    - How often?
- What motivated you as a healthcare provider to use mHealth?
- What elements of the intervention do you think are most important?
- Did you do any preparation before using mHealth to manage COPD?
- What is necessary for you to obtain knowledge/experience and keep up to date about mHealth?

**Barriers**

- What is limiting you from using mHealth in your practice?
- What difficulties have you experienced when using mHealth?
- How did you solve it?
- Were there any challenges?
    - (financial, employees, technical)?
- Did you experience changes in the contact/bond with the patient?
- Do HCPs require education before use and how did that happen in the past?
- Do patients require education before use and how did that happen in the past?

**mHealth in COPD Management**

- Do you see a role of mHealth in COPD management?
    - how do you feel about apps used in COPD management?
- Could you tell me about whether you would be interested in using it?
- How do you perceive using mHealth to manage COPD?
- What information do you want to collect from the patient?
    - Education (how often)
    - Survey (how often)
    - Care plan

    - Compatible medical devices (e.g. spirometer, pulse oximeter, medication adherence device)
- What else would you like it to do?
- What would you change, take away or add?
- What about any problems or concerns you can see with this?
- How does mHealth affect the current COPD management process?
- Did you have to do any practical changes in consultations to enable the intervention? (Time, follow-ups, other?)
- How about viewing large amount of data, e.g. heart rate, spirometry, survey?
- Does your patients see a role of mHealth in COPD management?
- How does your patients perceive using mHealth to manage COPD?
- Who do you think can be a candidate for this intervention? (What is it about the patient that makes them suitable or not?)

**Final questions**

- Would you recommend mHealth to a colleague?
    - if so, what would you emphasize?
- Would you like to add anything?
- Would you like to elaborate on anything I asked?

Thank you for participating in this study, your answers to these questions are very important to us , and we really appreciate you taking the time to complete this interview. Please contact me if you have any questions or would like to discuss this topic further.

# Appendix 2 - Patient questionnaire

## A- Eligibility

**1. Have you been diagnosed by a physician as having Chronic Obstructive Pulmonary Disease (COPD), Emphysema, or Chronic Bronchitis?**

- ☐ Yes
- ☐ No (If you have not been diagnosed by a physician as having COPD, emphysema, or chronic bronchitis then we're sorry. You are not eligible to participate in this study. Please discard the questionnaire).

**2. How old are you?**

- ☐ 30- 34 years
- ☐ 35 - 44 years
- ☐ 45 - 54 years
- ☐ 55 - 64 years
- ☐ Age 65 or older

## B- Mobile Health Technology Ownership

**3. Do you own an iPad and/or tablet?**

- ☐ Yes
- ☐ No

**4. Do you own a mobile/cell phone?**

- ☐ Yes
- ☐ No (skip to question 6)

**5. Is the mobile/cell phone you use a smartphone?**

- ☐ Yes
- ☐ No
- ☐ Don't know

**6. Other than you, does someone in your household have a smartphone?**

- ☐ Yes
- ☐ No

☐ Don't know ☐ Live alone

**7. Do you own any of the following health devices? Check all that apply**

☐ Spirometer/ Peak flow meter
☐ Glucose meter/ sugar level monitor
☐ Blood pressure monitor
☐ Heart rate monitor
☐ Activity counter (e.g. fitbit or apple watch)
☐ Scale
☐ Thermometer
☐ Insulin pump

☐ Other, please specify:_______________________________________

## C- Mobile Health Technology Use

**8. What language do you use on your phone?**

☐ English
☐ French
☐ Other, please specify:_______________________________________

**9. Do you use any of the social media accounts listed below? Check all that apply**

☐ Facebook
☐ Instagram
☐ Twitter
☐ Snapchat

☐ I do not use social media accounts (skip to question 11)

☐ Other, please specify:_______________________________________

**10. How often do you use your social media networks?**

☐ Never
☐ A few times a month
☐ A few times a week
☐ About once a day
☐ More than once a day

**11. Would you be interested in using social media to share your health experience with other people with similar health issues?**

☐ Yes
☐ No

**12. Do you know what a smartphone "app" is?**

☐ Yes
☐ No (Skip to question 21)

**13. Do you use apps on your smartphone?**

☐ Yes
☐ No (Skip to question 21)
☐ Don't know

**14. In the past 12 months, did you use health-related apps on your smartphone?**

☐ Yes
☐ No
☐ Don't know

**15. Would you be interested in using a smartphone app to improve your health?**

☐ Yes
☐ No (skip to question 17)

**16. If you are interested in using a health-related app, how often do you think you would you use it to improve your health?**

☐ Once a week

☐ Once a day

☐ 2-3 times per day

☐ 4-5 times per day

☐ 6 or more times per day

**17. What particular health-related app feature do you think would be useful? Check all that apply**

☐ Medication information
☐ Medication Reminders

☐ Inhaler technique education
☐ Nutrition information

☐ COPD action plan

☐ Mental wellness techniques

☐ General information about disease

☐ Other, please specify:_____________________________________

**18. Would you be comfortable allowing a family member or friend to access health-related information that you shared in an app?**

☐ Yes
☐ No

**19. Would you be comfortable allowing your family doctor or other healthcare professionals to have access to your health information that you shared in an app?**

☐ Yes
☐ No

**20. Which of the following concerns do you have about the use of smartphone applications (apps)? Check all that apply**

☐ They are not easy to use

☐ They take too much time to use

☐ I do not know if they are effective

☐ Apps use a lot of data

☐ There is an extra fee to use the app

☐ Worried about personal information disclosure

☐ Not recommended by a healthcare provider

☐ None of the above

☐ Other, please specify:_____________________________________

**21. Did you access the Internet from your phone during the past 12 months?**

☐ Yes
☐ No
☐ Don't know

**22. If you use the internet on your smartphone for health needs, which sites do you use? Check all that apply**

☐ Google

☐ WebMD

☐ Yahoo/Bing/Other search engines

☐ Mayo clinic/PubMed/NIH

☐ Wikipedia

☐ YouTube

☐ Other, please specify:________________________________________

**23. Which of the following concerns do you have about smartphones? Check all that apply**

☐ Cost of smartphones

☐ They are not easy to use

☐ Reducing face to face interaction

☐ None of the above

☐ Other, please specify:________________________________________

## D- Demographics and Health Information

**24. What is your sex?**

☐ Female
☐ Male

**25. What is your gender?**

☐ Female
☐ Male
☐ Prefer not to answer
☐ Other, please specify:________________________________________

**26. What is your Marital Status?**

☐ Married

☐ Common Law

☐ Single (never married)

☐ Widowed, Separated, or Divorced

☐ Prefer not to answer

**27. What is your highest level of education?**

☐ Less than high school

☐ High School Equivalency (GED)

☐ Bachelor’s degree

☐ Master’s degree

☐ High School

☐ PhD/ MD/ JD

☐ Prefer not to answer

☐ Other, please specify:______________________________________

**28. Which of the following best describes where you currently live?**

☐ Rural area, with a population less than 1,000

☐ Small population centre, with a population between 1,000 and 29,999

☐ Medium population centre, with a population between 30,000 and 99,999

☐ Large urban population centre, with a population of 100,000 or more.

**29. What best describes your employment ?**

☐ Employed full time

☐ Employed part time

☐ Self-employed

☐ Retired

☐ Student

☐ Unemployed

**30. What is the range that best describes your gross household income in the last year?**

☐ Under $20,000

☐ $20,000-$39,000

☐ $40,000-$59,000

☐ $60,000–79,000

☐ $80,000–150,000

☐ Over $150,000

☐ Don’t know

☐ Prefer not to answer

**31. What medical conditions do you have or have had in the past? Check all that apply**

☐ Diabetes

☐ Lung disease

☐ Heart disease

☐ Kidney disease

☐ Cancer

☐ Mental Health Issues

☐ Skeletal/ Muscular disease (e.g. Arthritis)

☐ Prefer not to answer

☐ Other, please specify:______________________________________

**32. How many medications do you take each day? This include medications you may buy**

**without a prescription**

- ☐ None
- ☐ 1-2
- ☐ 3-4
- ☐ 4-6
- ☐ More than 6
- ☐ Prefer to not answer
- ☐ Other, please specify:___________________________________

## E- Future Research

**33. Are you willing to participate in a focus group to help develop an app for COPD management?**

☐ Yes (Please answer question 36)

☐ No

**34. Are you willing to participate in an individual interview to help develop an app for COPD management?**

☐ Yes (Please answer question 36)

☐ No

**35. Are you willing to be contacted for future research?**

☐ Yes (Please answer question 36)

☐ No

**Thank you for participating in this study. Your answers to these questions are important to us, and we really appreciate you taking the time to complete this questionnaire.**

# Insert the completed form in the **BLUE** box located at the clinic

**36. If you answered yes to questions 33, 34 and/ or 35, please provide a phone number and/or email below to allow us to contact you.**

*Note that adding your contact information may present some privacy and confidentiality risks. There is always a small risk that data your answers to the questionnaire may be identified. We will use strict measures to protect your privacy.

Name:

Phone number:

Email:

Best time to call:

# Tear this page and insert it the **RED** box located at the clinic

# Appendix 3 - Patient Interview prompts

- Date
- Years living with COPD

## General perceptions

- Tell me a little bit about your experience with COPD?
- How do you know if your COPD is getting worse?
- How do you manage it?
- Do you have other chronic diseases besides COPD?
- How do you manage it along with your COPD?
- How many medications do you take?
- How do you remember when to take it?
- Do you own any health devices (e.g., spirometer, blood pressure monitor)?
- How often do you use it?
- Does it connect to your smartphone?
- What type of phone do you have?
    - How did you learn how to use it?
    - Do you live with someone who knows how to use it?
    - Does your friends/ family use a smartphone?
    - Do you know what a smartphone "app" is?
    - Do you use apps on your smartphone?
    - In the past 12 months, did you use health-related apps on your smartphone?
    - Did you access the Internet from your phone during the past 12 months?

## Facilitators

- Do you know what mHealth is? (using a phone to improve your health)
- Have you used mhealth before? (if no, go to barriers).
- Tell me about a situation when you have tried to use mhealth/ telehealth.
    - Why this episode?
    - What did you use it for?
    - What data did you collect?
    - How often?
- What motivated you to use mhealth?
- What elements of the intervention do you think are most important?
- Did you do any preparation before using mHealth to manage COPD?
- What is necessary for you to obtain knowledge/experience and keep up to date about mHealth?

## Barriers

- What is limiting you from using a smartphone?
- What is limiting you from using mHealth?

- What difficulties have you experienced when using mHealth?
- How did you solve it?
- Were there any challenges?
    - (financial, employees, technical)?
- Did you experience changes in the contact/bond with your healthcare provider?

## mHealth in COPD Management

- Do you see a role of mHealth in COPD management?
- How do you feel about apps used in COPD management?
- What features do you want the app to include?
    - Education (how often)
    - Survey (how often)
    - Care plan
    - Compatible medical devices ((e.g. spirometer, pulse oximeter, medication adherence device)
    - Health coach
- What else would you like it to do?
- How often do you think you would you use it to manage your COPD?
- Could you tell me whether you would be interested in using it?
- What about any problems or concerns you can see with this?
- Would you be comfortable allowing a family member or friend to access health-related information that you shared in an app? Why/ why not?
- Would you be comfortable allowing your family doctor or other healthcare professionals to have access to your health information that you shared in an app?Why/ why not?
- How does mHealth affect your current COPD management process?
- How about viewing a large amount of data, e.g. heart rate, spirometry, survey?
- Does your healthcare provider see a role of mHealth in COPD management?
- How does your healthcare provider perceive using telehealth/ mHealth to manage COPD?

## Final questions

- Would you like to add anything?
- Would you like to elaborate on anything I asked?

Thank you for participating in this study, your answers to these questions are very important to us, and we really appreciate you taking the time to complete this interview. Please contact me if you have any questions or would like to discuss this topic further.