Using Electronic Medical Records to Assess and Improve Primary Care Physicians' Performance of Chronic Disease Management in Ontario

by

Theresa Min-Hyung Lee

A thesis submitted in conformity with the requirements
for the degree of Doctor of Philosophy

Institute of Health Policy, Management and Evaluation
University of Toronto

Using Electronic Medical Records to Assess and Improve Primary Care Physicians' Performance of Chronic Disease Management in Ontario

Theresa Min-Hyung Lee

Doctor of Philosophy

Institute of Health Policy, Management and Evaluation
University of Toronto

2020

Abstract

Through five original studies, this thesis studies if and how electronic medical records (EMRs) can be used meaningfully to target improvements in chronic disease management in primary care practices in Ontario. The thesis answers four areas concerning primary care EMRs. First, it identifies if EMRs can be used to accurately identify patients with chronic disease (COPD). Second, it studies if EMR systems can measure primary care physicians' adherence to clinical practice guidelines for patients with respiratory or cardiovascular diseases (CVD) or risk. Third it looks at if EMRs can be used to assess provider or patient characteristics that are associated with the provision or receipt of guideline adherent care respiratory or vascular disease management. Finally, this thesis examines the barriers to and facilitators for the adoption and routine use of EMR tools designed to increase guideline-adherence in primary care. Identifying patients with certain conditions is essential to target quality improvement initiatives and audit current performance. The thesis demonstrates that EMRs could be used to accurately identify patients with COPD. Aspects of chronic disease care, namely primary care physicians' adherence to clinical practice guidelines and quality indicators for CVD and COPD are possible to measure when they are quantifiable or coded in semi-structured or structured formats in the EMR. It is possible to link EMR data to external data sources to investigate if there are provider or patient characteristics associated with meeting the quality indicator criteria (including the effects of health service utilization data, socioeconomic data and clinical data). This thesis provides insight

into important considerations for building a quality improvement intervention using EMR data as a platform or data source by identifying key barriers to, and facilitators for the adoption of EMR-based tools designed to increase guideline-adherence in primary care. We identified key limitations to using EMR data to measure primary care quality, which would be important to consider in future efforts to use EMRs for primary care quality improvement and performance management. It is essential that policymakers take into consideration sociotechnical aspects of the healthcare system and delivery when considering the use of EMRs for quality improvement.

Dedication

This thesis is dedicated to my family.

In loving memory of my grandfather Kim Hakmoo, and my grandmother An Young-Im.

To my parents, Bartholomew Sanghyeon Lee and Catharina Miok Lee who have taught me the value of hard work.

盡人事待天命
(Jin in sa dae cheon myeong)

Acknowledgements

This thesis was made possible with the unwavering support of my co-supervisors, Dr. Karen Tu and Dr. Andrea Gershon. Thank you for your guidance and mentorship from the beginning. I am grateful that I had the opportunity to work alongside and learn from great mentors who were both gracious in sharing their knowledge and expertise to help me become a better researcher. I am so fortunate to have worked with two role models who exemplified research excellence, authenticity, strength and collaborative leadership during my academic journey.

I am grateful for my committee members, Dr. Noah M. Ivers and Dr Jan Barnsley, who always provided their invaluable feedback and shared their expertise in primary care and quality improvement to enhance my work. Noah, thank you for giving me the opportunity to see the reality of primary care practice at your clinic and Jan, thank you for helping me develop my foundations in health services research. Thank you both for your support.

I am also grateful for the support from Dr. Sheldon Tobe, Dr. Debra Butt, Dr. Liisa Jaakkimainen, Kim Walker, Dr. Peter Liu, and the Canadian Vascular Network for the work in this thesis related to Canadian Cardiovascular Harmonization of National Guidelines Endeavour (C-CHANGE). Thank you also to Lily Ye for helping me interview, transcribe and code.

To the staff at ICES and the EMRALD® team, past and present, who supported me in completing my thesis, especially, Jacqueline Young, Laura Wing, Daniel Legge, Bogdan Pinzaru, Shirin Jabbari, Daniela Cortinovis, and Christopher Meaney, thank you. Thank you to the physicians that contribute their EMR charts to EMRALD® who made this research possible.

I am grateful to the community, faculty, staff and students of University of Toronto and the Institute of Health Policy, Management, and Evaluation (IHPME), in particular, I owe my thanks to Dr. Rhonda Cockerill, Dr. Emily Seto, Dr. Aviv Shachak, Dr. Joseph Cafazzo, and Kerstin Giannini for helping me get started and helping me get through. I am grateful to the IHPME-Graduate Students' Union, and fellow classmates and friends, for their solidarity, keeping me connected and grounded along the way, especially, Serena Purdy, Nelson Shen, Austin Nam, Sarah Carsley, Avi Biswas, Rossini Yue, Michael Lebenbaum, Nusrat Farhana and Krishana Sankar. Serena and Krishana, thank you for the countless hours you have joined me in coffee shops and libraries. It was easier to break through the impasses in the final months when writing in good company.

I am blessed to be surrounded by loving family and friends. Thank you, mom, dad, Paul and Jena for your love and support. To my friends, Stephanie Kao, Samantha Kearney, David Jiang, Jeremy Tsui, Priscilla Tang, Rachel Li and Valerie Mize, thank you for being my support system near and far. Thank you especially to Daniel Bowie who has read and reviewed everything I wrote and encouraged me to get to the finish line.

This thesis was also made possible with the funding support from numerous organizations. I would like to thank the generosity from the Rathlyn Foundation and their Primary Care EMR Research and Discovery Fund.

Funding for Chapters 2 and 4 was provided by the Province of Ontario through the MOHLTC Health Systems Research Fund Capacity Grant. Chapters 2 and 4 were also supported by the Canadian Respiratory Research Network (CRRN), which is supported by grants from the Canadian Institutes of Health Research (CIHR) - Institute of Circulatory and Respiratory Health; Canadian Lung Association (CLA)/Canadian Thoracic Society (CTS); British Columbia Lung Association; and Industry Partners Boehringer-Ingelheim Canada Ltd, AstraZeneca Canada Inc., and Novartis Canada Ltd. Funding for training of graduate students and new investigators within the network was supported by the above funding Sponsors and as well by GlaxoSmithKline Inc. The funders had no role in the study design, data collection and analysis, or preparation of the thesis.

Chapters 3 and 5 were funded by the Canadian Institute of Health Research as part of the Institute of Circulatory and Respiratory Health Emerging Network Grants competition through the Canadian Vascular Network Seed Funding Award (grant number 132211).

Chapter 6 received funding support from the Ontario Renal Network.

The research in this thesis was supported by the Institute for Clinical Evaluative Sciences (ICES), which is funded by an annual grant from the Ontario Ministry of Health and Long-Term Care (MOHLTC). The opinions, results and conclusions reported in this work are those of the author and are independent from the funding sources. No endorsement by ICES or the Ontario MOHLTC is intended or should be inferred.

Parts of this material are based on data and information compiled and provided by the Canadian Institute for Health Information (CIHI). However, the analyses, conclusions, opinions and statements expressed herein are those of the authors, and not necessarily those of CIHI.

Table of Contents

List of Tables

List of Figures

List of Plates

List of Appendices

List of Abbreviations

2hPG - 2-hour plasma glucose

ACE - angiotensin-converting enzyme

ADG - aggregated diagnosis group

AFib – Atrial fibrillation

AMI - Acute myocardial infarction

ARB - angiotensin II receptor blocker

ASA - acetylsalicylic acid

BMI - body mass index

BP - blood pressure

C-CHANGE – Canadian Cardiovascular Harmonized National Guideline Endeavour

CABG - coronary artery bypass grafting

CAD - coronary artery disease

CCB - Calcium channel blocker

CHF – congestive heart failure

CIHI – Canadian Institute for Health Information

CKD - chronic kidney disease

COPD – chronic obstructive pulmonary disease

CPCSSN – Canadian Primary Care Sentinel Surveillance Network

CRRN – Canadian respiratory research network

CVD – cardiovascular disease

ECG - electrocardiograph

EMR – electronic medical record

EMRALD® - Electronic Medical Record Administrative data Linked Database

FP – family physician

FPG - fasting plasma glucose

HbA1c - Hemoglobin A1c

HIV - human immunodeficiency virus

HQO – Health Quality Ontario

ICES – Institute for Clinical Evaluative Sciences (Ontario, Canada)

IGT - impaired glucose tolerance

IOM – Institute of Medicine

IQR – inter-quartile range

IS – information system

LAAC – long-acting anti-cholinergic

LABA – long-acting beta-agonist

LVEF - left ventricular ejection fraction

MOHLTC – Ministry of Health and Long-Term Care (Ontario, Canada)

NPT – normalization process theory

OGTT - oral glucose tolerance test

OPHN – Ontario Population Health Network

PCI - percutaneous coronary intervention

PCP – primary care physician

PFT – pulmonary function test

QI - quality indicator

§Roster – in Ontario, insured individuals can belong to a family physician's roster. Being rostered to the family physician means that the patient regularly sees the same family physician and the family physician is the most responsible primary care physician (as opposed to a physician in the emergency room or from a walk-in clinic). ** to change

SAAC – short-acting anticholinergic

SABA – short-acting beta agonist

SBP - systolic blood pressure

SD – standard deviation

SQL - structured query language

Chapter 1

Introduction

The purpose of this chapter is to:

1. Provide an overview of the thesis and describe the contents of each chapter;
2. Provide an introduction to electronic medical records (EMRs) and their use in primary care;
3. Discuss the results and limitations of research efforts in Canada related to the use of EMRs for quality improvement in chronic disease management;
4. Present the research questions; and
5. Outline the theoretical framework used in this thesis.

1.1 Introduction

Electronic medical records (EMRs) are electronically stored health records of patients in the form of documents and images, which are usually maintained by a single primary care facility or system. The electronic nature of these health records enables primary care physicians, pharmacists, nurses and other health professionals to easily store, retrieve and manipulate patient encounter information, potentially allowing for improved communication and patient safety. In particular, the *meaningful use* of EMRs may benefit health care systems by increasing efficiencies such as reducing the number of duplicate tests, reducing adverse drug events and improving overall health outcomes. In 2001, an independent, not-for-profit pan-Canadian organization called Canada Health Infoway was established and funded by the federal government to accelerate and coordinate the development and adoption of digital health solutions, including EMRs, across all provinces and territories. It was only in recent years that EMRs have been adopted by the majority of family physicians. The future direction of EMRs is of importance in health informatics research, as EMRs may play a growing role in strengthening the primary health care system. Despite this importance, there is still limited knowledge on how EMRs are being used for the benefit of population health. This thesis will focus on the use of EMRs in primary care in the province of Ontario.

1.2 Thesis overview

This thesis contains seven chapters discussing the use of electronic medical records for chronic disease management and quality improvement in primary care. The overall objective of the thesis is to study if and how EMRs can be used to measure and improve the quality of chronic disease management in primary care practices in Ontario. The ultimate goal is to use the findings from the research to increase the use of EMRs as a tool to improve the health of the population.

Chapter 1 provides background information and establishes the motivation for the thesis, poses the research questions being investigated and introduces the theoretical perspective guiding the study design.

Chapter 2 contains a retrospective chart abstraction study that demonstrates how primary care EMR data can be used to identify patients with complex chronic disease. Specifically, the study develops and validates an EMR algorithm for finding patients with physician-diagnosed COPD chronic obstructive pulmonary disease (COPD).

Chapter 3 describes the development of quality indicators based on the Canadian Cardiovascular Harmonized Guidelines Endeavour (C-CHANGE) recommendations, and how primary care EMR data can be used to measure quality indicators to assess care patterns in the area of cardiovascular disease (CVD) management.

Chapter 4 reports on the feasibility and limitations of using primary care EMR data to measure existing quality indicators for COPD, based on the case-finding algorithm presented in Chapter 2. Specifically, EMR data is used to assess COPD care received by patients at the population level and how care patterns varied between family physicians (FPs).

Chapter 5 describes a quantitative cross-sectional study that links EMR data with administrative data to identify patient or physician factors associated with the CVD guideline adherence, as measured in Chapter 3.

Chapter 6 presents a qualitative study that identifies challenges and barriers to adopting EMR tools in primary care for quality improvement and chronic disease management.

Chapter 7 summarizes and synthesizes the preceding findings of Chapters 2 to 6, discusses the limitations and implications of this work and suggests some potential future research directions.

1.3 Background

1.3.1 Electronic medical records and meaningful use

Billions of dollars of support from national organizations such as Canada Health Infoway,[1] backed by federal grants and provincial government programs,[2–4] has led to an increased uptake of EMRs across Canada. As a result, the number of Canadian physicians reporting EMR use has more than doubled from 23% in 2006 to 56% in 2012, and in the most recent Canadian Physician survey, 86% of Ontario family physicians reported using an EMR.[5] It is expected that a further investment of $350 per capita between 2015 and 2025 is required to achieve the vision of an integrated information system across the country.[6] Although the uptake of EMRs is growing, there is still a demand from governments, investors and users for evidence of ‘meaningful use’ of EMR systems showing benefits for health care systems.[7,8] While EMR adoption has increased, there remains limited knowledge about the broader challenges regarding EMR use in primary

care settings, and there is a need to ascertain the value of EMRs as well as to understand the elements of its implementation and adoption to advance its use.[9]

The concept of 'meaningful use' in the context of the United States and its definition based on the Health Information Technology for Economic and Clinical Health (HITECH) Act[10] originated from the pillars of health outcomes policy priorities, such as improving quality, safety, efficiency, and reducing health disparities; engaging patients and families in their health; improving care coordination; improving population and public health; and ensuring adequate privacy and security protection for personal health information. While no equivalent act was mandated in Canada, the issue of meaningful use of EMRs is also highly relevant to Canadian primary care where they are being increasingly adopted.

1.3.2 Role of EMRs in primary care quality improvement

The potential to meaningfully use EMR data to capture health information and improve population health through continuous quality improvement in primary care is particularly interesting. Primary health care is an integral cornerstone of a strong health care system, and it has been the focus of governments interested in improving health care systems.[11] According to the Commonwealth Fund's International Health Policy Survey of primary care physicians and the public, Canadian primary health care consistently ranks poorly compared to other developed nations.[12,13] Where it lacks the most is in access (e.g., timeliness and after-hours care) and infrastructure (e.g., widespread adoption of electronic medical records). There is also low participation in quality improvement, slow uptake of information technology, poor access to care (in relation to other countries), wide variation in avoidable hospitalizations, and suboptimal prescribing trends[14–16]. Primary care is pivotal to addressing and achieving healthy populations, prevention of disease, management of chronic conditions, and sustainability of a health care system, yet there has been limited coordination to collect, analyze and report on its performance. Without data on performance trends over time and peer comparisons, primary care providers have limited capacity to generate their own performance data and implement essential quality improvement.

EMRs can potentially be used to improve quality of primary care. This is predicated on its meaningful use including accurate and complete recording of data to enable measurement for quality indicators, and application of tools embedded within the EMR for quality improvement.

Thus, EMRs can be used as both a tool and a source of data to study chronic health conditions that cause large socioeconomic burden. This thesis will study how EMRs could be used in the context of improving chronic diseases that affect a large subset of the Canadian population, including CVD and COPD.

1.3.3 Role of EMRs in improving the management of chronic diseases

CVD places significant burden on the Canadian population, and includes conditions that affect the circulatory system such as atrial fibrillation, heart failure, and chronic kidney disease (CKD) that increase the risk of events such as stroke or heart attack[17]. More than three million Canadians are affected by CVD, and the financial burden on the health care system is staggering, at upwards of $30 billion.[17] CVD is the leading cause of preventable death and disability nationwide, and its impact continues to grow.[17] As the number of Canadians with risk factors for CVD climbs, the prevention, management, and improvement of these conditions in primary care will become more important.

COPD is characterized by persistent airflow limitation and an enhanced chronic inflammatory response in the airways to noxious particles or gases such as tobacco smoke.[18] Prevalent in over 10% of the population, Canadians' lifetime risk of developing COPD is more than 25%.[18] It is the most common cause of hospitalization in Canada and the third leading cause of death worldwide[19–22]. Studies project an increase in morbidity and mortality from COPD due to the delayed effects from the progressive increase in the prevalence of smoking observed in previous years, and an aging demographic[23]. Due to management targets becoming more preventive than reactive, the management of COPD is shifting from the secondary to the primary care setting[24].

Improvement of chronic disease management in primary care at a system level entails monitoring quality of care over time and across patients and practices[25]. Previous research has shown that patients with chronic conditions often do not receive the care recommended for them on the basis of best available evidence[25–31] demonstrated by system-wide variation in avoidable hospitalization and sub-optimal prescribing trends.[14] This highlights the need for improved practice and knowledge translation among primary care physicians, which can potentially be met with the use of EMRs.

1.3.4 Use of EMRs in improving the quality of primary care and chronic disease management

With the increasing adoption of EMRs, there is a need for investigation of meaningful secondary uses of EMRs beyond patient record keeping[32,33]. It remains unclear how EMRs can best be harnessed to further health services research, increase our understanding of the population, and improve the quality of our healthcare[34]. In Canada, it has been a challenge to achieve a high degree of EMR adoption as well as EMR maturity[7], but its uptake has grown in the last few years, with the majority of family physicians in Ontario having adopted EMRs.[12] High maturity from EMRs and surrounding IT infrastructure allow external data linkages to be built and queries of advanced clinical questions for health services research and population analysis.[35] Health care services research with EMRs is growing and innovating, and there is evidence in the literature featuring novel ways to use EMRs linked with additional data sources to answer health service research questions.[36] Traditionally, public health establishments have analyzed population health status and problems through surveys, vital statistics reporting, and paper-based methods[37]. However, there are limitations to these methods, such as limited sample sizes, recall bias or error, and high cost.

A review of the literature demonstrated that there was advanced use of EMRs to identify and study CVD and COPD in primary care. Several studies were identified that showed the feasibility of using EMR or administrative databases to identify patients with different types of vascular diseases[38–40]. Two papers also looked at risk factors associated with specific vascular disease, such as hypertension[41,42]. Other studies have used EMRs to look at predictive variables within populations for deep vein thrombosis, to assess clinical interventions[43,44], or used EMR databases as a surveillance tool for adverse drug events in a target population or for medication adherence[33,35,45–49]. Some studies used EMRs to assess adherence to process and outcome measures for chronic illnesses, such as monitoring blood pressure, lipids, glycosylated haemoglobin, or provide feedback to clinicians on their rates of adherence to clinical guidelines[50–53].

Previous work evaluating the burden of COPD has primarily been based on cross-sectional survey data and cohorts in specific populations[22] but there is growing evidence of using EMRs to study this condition in greater depth. Self-reported measures for COPD have been validated against clinical records and physician diagnosis showing mixed results in the level of accuracy of

self-report, thus additional information contained in EMRs would provide further diagnostic confirmation[54–57]. In addition, the cross-sectional nature of survey data means that direction of association is not possible to determine[54]. More recently, researchers have looked to other population-based data sources to study COPD, such as administrative claims databases[58–62], but are limited in the depth and accuracy of details of patient clinical information because they are created to manage financial transactions rather than for research purposes or patient care[63]. A limited number of studies validating the diagnosis of COPD using case definitions in EMRs have been done in the UK and in Canada[39,64–67]. Some of the challenges to identifying people with COPD in EMRs relates to differentiating it from other respiratory conditions, and limited records of diagnostic tests such as pulmonary function tests (PFTs) or spirometry in the EMR from either limited use or limited recording in the EMR of its use.

In addition to calculating the prevalence of COPD using EMR data[24], EMR data have been used in studies examining risk factors associated with the development or exacerbation of COPD[68,69]; evaluating COPD intervention programs in Finland[70]; calculating the risk of adverse cardiac and respiratory events associated with different COPD drugs in the UK[71]; and medication utilization patterns among COPD patients.[72] There are currently ongoing initiatives to develop and improve respiratory data elements and standards in EMRs to facilitate evidenced-based clinical care, monitoring, surveillance, benchmarking and policy development.[27] As well, headway has been made in using EMRs and electronic order sets for improving the management of acute exacerbation of COPD, such as improved compliance with clinical practice guidelines and reduction in the total dose of corticosteroid administered in patients hospitalized for acute COPD exacerbations.[73] Further research is required for the realization of an ideal analytic platform that can combine the clinical details and depth of EMR data with population-wide health administrative data to provide a comprehensive COPD surveillance and research program.

EMRs have been increasingly used in the provision of care, surveillance, research, and informing practice in primary care[65], however it is not yet clearly understood how EMRs can optimally support quality improvement in primary care chronic disease management. While it is important to assess the various capabilities of EMR systems (e.g., ability to identify patients with specific conditions, ability to measure adherence to clinical practice guidelines, ability to construct statistical models to answer population health based questions), the results would be inconsequential if physicians were not willing to adopt them for quality improvement initiatives.

Therefore, in order to increase the meaningful adoption and use of EMRs, it is essential to investigate the factors that influence the uptake of EMR tools for quality improvement.

There is evidence that implementation of EMRs provide some benefits to clinical care, particularly at the in-patient setting. For example, computerized physician order entries reduce medication prescription errors.[74] Further, there is a growing body of evidence that EMRs can be used to study diabetes care and hypertension[75], particularly process and outcome indicators that can identify opportunities for clinical improvement. Several observational studies have shown EMRs can reduce hospitalizations from diabetes, and that they can be used to build disease registries, develop clinical decision support systems, and integrate with other patient self-management tools.[76] Other studies have shown that access to EMR data improves physicians' ability to detect, treat, and control chronic conditions like hypertension.[77] However, quality of care for other burdensome chronic conditions including COPD[18–22] and cardiovascular disease[17] have been less well studied with EMR data in Canada. It has been observed in the literature that there are opportunities for improvement of management of these conditions.[25–31] Unfortunately, there is no systematic, ongoing mechanism to provide feedback on performance trends to primary care physicians nationally or provincially in Ontario. Furthermore, there are gaps in data availability at practice- and system-levels to measure quality of primary care.[78] There is currently insufficient evidence on how EMRs can be used to measure and improve the quality of chronic disease management in primary care in Ontario.

In this research project, we investigate how EMRs can be used as a source of data to measure the performance of clinicians, and how it could be used as a tool to improve the quality of chronic disease management in primary care practices in Ontario. This research employs the principle of mixed methods pragmatism through a multi-phase research design informed by theoretical frameworks that extend across disciplines of health services research, health informatics and implementation science. The first four studies involve analysis of EMR data available in the Electronic Medical Record Administrative data Linked Database (EMRALD®) housed at the Institute for Clinical Evaluative Sciences (ICES). This phase will consist of quantitative analysis of primary care practice data to study chronic disease management in Ontario. The last phase consists of primary data collection and analysis of qualitative data using semi-structured interviews to identify the potential barriers and facilitators associated with adoption of EMR tools for quality improvement in primary care practice. In this thesis, the 'meaningful use' of

EMRs is defined as capturing and using health information in the EMR for the purpose of improving population health through continuous quality improvement in primary care.

1.4 Research questions

The extent of meaningful use of EMRs in Ontario is not well known, and there is limited research on the benefits of EMRs in primary care settings. The overall objective of this project is to answer an overarching research question:

> *Can EMRs be used to measure and improve quality of chronic disease management in primary care practices in Ontario?*

Using a multi-phase mixed method design, the five studies presented in Chapters 2 to 6 explore the potential for EMRs to identify and improve gaps in primary care. Specifically, they seek to understand some of the barriers and facilitators to providing guideline-adherent care in primary care with the support of EMR tools. They address the following questions:

1. Can EMRs be used to accurately identify patients with chronic diseases such as COPD?
2. Can EMRs be used to measure primary care physicians' adherence to clinical practice guidelines for patients with chronic diseases, specifically CVD and COPD?
3. Can EMR data be used to identify provider or patient characteristics that are associated with the provision or receipt of guideline adherent care in chronic disease management?
4. What are the barriers to, and facilitators for, the adoption of EMR-embedded tools designed to increase guideline-adherence in primary care at the provider and organizational level?

1.5 Theoretical perspective

Reflective of its interdisciplinary nature, this research study draws on two theoretical and conceptual frameworks, with constructs from health informatics, health services research and implementation science. Theories provide a coherent conceptual arrangement that, when operationalized, makes it possible to describe, categorize and explain phenomena and constructs rationally and systematically.[79] The frameworks described below will be used to define what is meant by the concept of 'quality' and the mechanism by which EMRs are adopted in an organization for quality improvement.

1.5.1 Quality of primary care and clinical practice guidelines

The definition of 'quality' in healthcare is multi-dimensional. The working definition of quality will be based on Health Quality Ontario's (HQO) attributes of quality, and this research will focus on the aspects of quality that are targeted by clinical practice guidelines.

HQO has identified nine attributes of a high-performing health care system outlined Table 1-1.[80] The nine attributes are: access, patient-centredness, integration, effectiveness, focused on population health, efficiency, safety, appropriate resources, and equity. These attributes of quality are adopted within the Excellent Care for All Act[81] and are similar to dimensions of quality as defined by the Institute of Medicine's transformative work, *Crossing the Quality Chasm: A New Health System for the 21st Century.*[82]

Clinical practice guidelines are based on scientific evidence and expert consensus, and serve to define standards of care, facilitate the decision-making process for the treatment of specific diseases,[83] and focus the efforts of health care workers on improving quality.[84] These guidelines can also be used as a mechanism for disseminating knowledge about evidence-based care to clinicians. Here, evidence-based care refers to 'the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients'.[85] When adopted correctly and widely, clinical practice guidelines can help improve each of the nine attributes of a quality health care system. Clinical practice guidelines are considered essential instruments to improve the quality of care,[82] as they have been found to improve patient outcomes, reduce practice variation and reduce costs.[86,87] Thus, adherence to recommendations from evidence-based clinical guidelines will be used as quality indicators and a measure of quality in this thesis research.

Variation among health care providers in their compliance to well-accepted guidelines can be indicative of a gap in quality of care, or could bring into question the validity of the guidelines.[88] Measuring the adherence to clinical practice guidelines across a jurisdiction indicates quality of care at a population level. Patterns of wide variation in health care practice (regionally or locally) suggest health care efficiency and effectiveness may be suboptimal, and highlights the importance of examining the relationship between health policy decisions and clinical decisions.[89] Previous studies have shown that variation among practices in referrals, per capita spending, resource allocation and service use is unwarranted as these variations are not explained

by illness or patient preference.[89] If the findings are based on evidence that scientifically well accepted, variation in practice suggests that not all clinical practices have kept pace with scientific evidence of best practices in health care.[88] Variations in practice patterns can indicate if inequities or disparities in quality exist, such that certain groups of the population are less likely than others to receive evidence-based care.[88] It is suggested that the adoption of health information systems and EMRs can support improvements in care practice through collection of data and decision support capabilities. In this thesis, performance and quality indicators based on clinical practice guidelines will be used to measure the quality of primary care across Ontario as it relates to CVD and COPD management.

1.5.2 Normalization Process Theory

Normalization Process Theory (NPT) (Figure **1-1**) describes how new practices are implemented, routinely embedded and integrated in everyday life through coherence, cognitive participation, collective action and reflexive monitoring.[79] This theoretical framework has been chosen to describe the factors that determine the usefulness of EMRs as a tool for quality improvement in primary care, at both the organizational and individual levels.

Given that the adoption and use of health IS tools such as EMRs takes place within a sociotechnical system, and is not dependent solely on information or system quality,[90] NPT was used to inform the design and analysis of the final qualitative research phase of this project, and acts as the underpinning theoretical framework to elucidate information on factors promoting or inhibiting the uptake of EMR tools designed to improve clinical practice in primary care practices.

The terms implementation, embedding, integration and normalization are core components of NPT. Implementation refers to purposive direction and social organization of bringing practices into action.[91] Embedding refers to the processes through which practices become routinely incorporated in everyday work.[91] Integration is the process by which practices are reproduced and sustained among the social matrices of an organization.[91] Normalization refers to the work that actors engage with an ensemble of activities, new or changed ways of thinking, acting, and organizing by which it becomes routinely embedded in pre-existing, socially patterned knowledge and practices.[92]

NPT is a conceptual arrangement describing the implementation, embedding and integration of practice through four processes:[92]

- 'Coherence' refers to the extent to which a technology or health practice must make sense to targeted stakeholders and actors.
- 'Cognitive participation' refers to the commitment and collective engagement of stakeholders to partake in the intervention.
- 'Collective action' refers to the relationship and work required that enables a new intervention to be taken up in practice and identifying the barriers to implementation and embedding.
- 'Reflexive monitoring' concerns continuous processes of evaluation to generate feedback and refine the object of implementation in order to embed it in everyday practice.

NPT has been used to understand how complex practices such as health care interventions are made workable and integrated in context-dependent ways.[79] Objects of implementation have included clinical guidelines and EMRs.[93–95] NPT was used to inform the development of the final interview protocol, in the design of open-ended semi-structured research questions, and was the underpinning conceptual framework by which the framework analysis was conducted in the final study of this research program. NPT was used to attempt to understand what factors promote or inhibit the uptake of EMR tools designed to improve clinical practice in primary care practices, and for explaining why EMR tools for quality improvement were adopted in some clinics but not others.

1.6 Electronic Medical Record Administrative data Linked Database (EMRALD®)

The main data source for this research is the Electronic Medical Record Administrative data Linked Database (EMRALD®) housed at the Institute for Clinical Evaluative Sciences (ICES). EMRALD® is a primary care EMR database that consists of all recorded clinical information from the EMRs of participating primary care physicians (PCPs). This includes all clinical information recorded by the family physician during patient visits, the cumulative patient profile (CPP), a presentation of past and current clinical history, and numerous text entries containing

information about items such as allergies, immunizations, referrals to specialists, consultation reports, prescriptions, diagnostic test results, lab test results, billing history and clinical reminders, among others. EMRALD® is linked to the health administrative databases held at ICES for all patients insured in Ontario and can be linked to further information including physician and hospital billing, socio-demographic information, dispensed drugs for those over the age of 65, and the discharge abstract database. ICES is a 'prescribed entity' under Ontario's patient privacy legislation and thus is able to collect individual level patient health information without patient consent based on policies and procedures in place to protect patient privacy and confidentiality for the purpose of studying and monitoring aspects of the health system.[96]

Currently, EMRALD® contains EMR data volunteered from approximately 2.5% of all family physicians in Ontario[97], with distribution throughout rural and non-rural Ontario. The average length of time on the EMR of contributing physicians has been approximately 5 years. EMRALD® physician characteristics are similar to all Ontario physicians in terms of geographic location and years in practice but differ from the overall population in three aspects: there are slightly more female physicians; physicians are less likely to have received foreign training; and physicians are younger.[98] While the patients in EMRALD® differ from the overall population in two aspects (they are slightly skewed towards the higher income quintiles and rural locations relative to the Ontario population), the distribution of age, sex, presence of chronic conditions and measures of comorbidity were similar to rostered patients in Ontario.[99] There is also a slight over-representation of older adults and a slight under-representation of youth. This slight distortion from the general population is likely typical of the types of patients that seek medical care from family physicians and not specific to EMRALD® participating physicians.[99]

1.7 Ethics approval

Research ethics approval was obtained for all five studies through Sunnybrook Research Institute's REB (via ICES privacy impact assessment) and gained REB administrative approval through University of Toronto REB for all studies.

Informed oral consents were obtained from all physician participants prior to the semi-structured interviews conducted in the qualitative study described in Chapter 6.

1.8 Dissertation outline

The objectives of this dissertation are addressed in five original studies described in chapters two to six. The final chapter is a general discussion that summarizes the findings of each study, synthesizes the major findings, discusses the strengths and limitations, outlines implications for policy and practice, public health and research, and describes suggestions for future research.

1.9 Tables and Figures

Table 1-1 Nine attributes of health care quality as defined by Health Quality Ontario[80]

Attribute	Description
Access	Accessible care refers to getting timely and appropriate healthcare services to achieve the best possible health outcomes.
Patient-centredness	Patient-centredness refers to the provision of services from health care providers in a way that is sensitive to an individual's needs and preferences.
Integration	Integrated care refers to all parts of the health system working together in an organized, connected fashion, and working with one another to provide high quality care.
Effectiveness	Effective care refers to the provision of care that works and is based on the best available scientific information.
Focused on population health	Care that is focused on population health refers to preventing sickness and improving the health of the people of Ontario.
Efficiency	Efficient care refers to a system that continually looks for ways to reduce waste, including waste of supplies, equipment, time, ideas and information, such as avoiding repeat tests or waiting for reports to be sent from one physician to another.
Safety	Safety refers to reduction in harm by accident or mistakes when people receive care.
Appropriate resources	Appropriately resourced care refers to a health system that has enough qualified providers, funding, information, equipment, supplies and facilities to look after people's health needs.
Equity	Equitable care means people should get the same quality of care regardless of who they are or where they live.

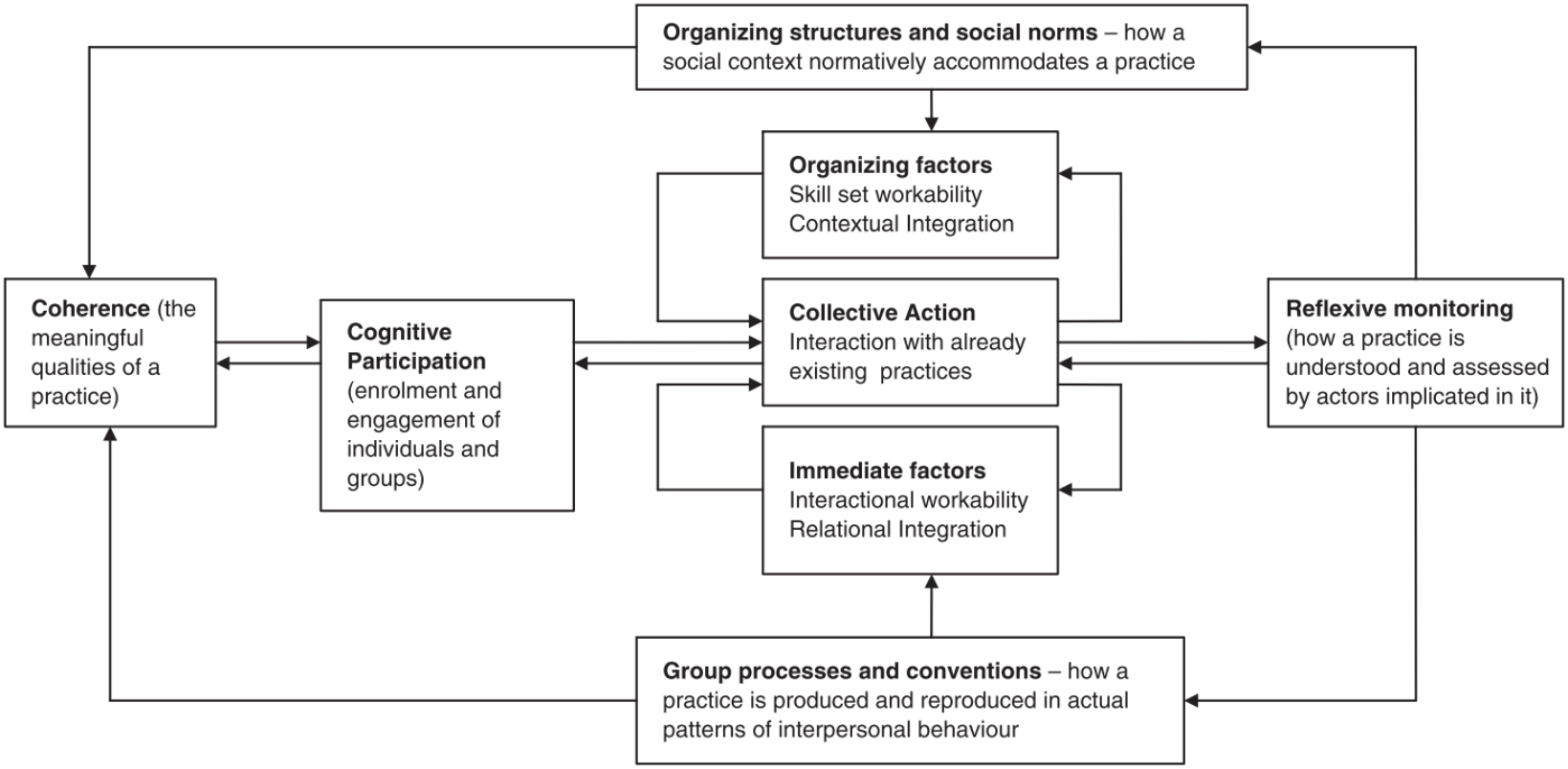


Figure 1-1 Normalization Process Theory (May & Finch, 2009)[79]*

* Reprinted by permission from SAGE: Sociology Copyright 2009. May, C. & Finch, T. Implementing, Embedding, and Integrating Practices: An Outline of Normalization Process Theory. *Sociology* **43**, 535–554 (2009). Figure 1, Model of the components of normalization process theory; p. 541.

Chapter 2

Identifying individuals with physician-diagnosed chronic obstructive pulmonary disease in primary care electronic medical records: a retrospective chart abstraction study

The purpose of this chapter is to answer the question, "can EMRs be used to accurately identify patients with chronic diseases such as COPD?" Identifying patients with specific chronic diseases is necessary to measure the quality of care and management of that chronic disease. A modified version of Chapter 2 was published in the journal Nature Partner Journal Primary Care Respiratory Medicine as an original research paper (Figure **2-1**). The objectives of this chapter are to:

1. Evaluate if data contained in a primary care EMR database can be used to adequately identify patients with chronic obstructive pulmonary disease (COPD).

2. Develop a validated algorithm to identify a cohort of patients with COPD in Ontario.

3. Gain an understanding of the components of EMR that impact accuracy and validity of case-finding for a complex condition such as COPD.

npj | Primary Care Respiratory Medicine

ARTICLE OPEN

Identifying individuals with physician-diagnosed chronic obstructive pulmonary disease in primary care electronic medical records: a retrospective chart abstraction study

Figure 2-1 Lee TM, Tu K, Wing LL, Gershon AS. Identifying individuals with physician-diagnosed chronic obstructive pulmonary disease in primary care electronic medical records: A retrospective chart abstraction study. *npj Prim Care Respir Med*. 2017;27(1):1-5. doi:10.1038/s41533-017-0035-9

2.1 Abstract

Background: Little is known about using electronic medical records (EMRs) to identify patients with chronic obstructive pulmonary disease (COPD) to improve quality of care. Our objective was to develop EMR algorithms that can accurately identify patients with COPD.

Methods: A retrospective chart abstraction study was conducted on data from the Electronic Medical Record Administrative data Linked Database (EMRALD®) housed at the Institute for Clinical Evaluative Sciences. Abstracted charts provided the reference standard based on available physician-diagnoses, COPD-specific medications, smoking history and pulmonary function testing (PFT). COPD EMR algorithms using combinations of terminology in the cumulative patient profile (CPP) (problem list/past medical history), physician billing codes (chronic bronchitis/emphysema/other COPD), and prescriptions, were tested against the reference standard. Sensitivity, specificity, and positive/negative predictive values (PPV/NPV) were calculated.

Results: There were 364 patients with COPD identified in a 5889 randomly sampled cohort aged $\geq$ 35 years. (prevalence=6.2%). The EMR algorithm consisting of $\geq$3 physician billing codes for COPD per year; documentation in the CPP; long-acting muscarinic antagonist prescription; or short-acting anticholinergic prescription and a COPD billing code had sensitivity of 76.9% (95%CI:72.2-81.2), specificity of 99.7% (99.5-99.8), PPV of 93.6% (90.3-96.1), and NPV of 98.5% (98.1-98.8).

Interpretation: EMR algorithms can accurately identify patients with COPD in primary care records. They can be used to enable further studies in practice patterns and COPD management in primary care.

Keywords: Chronic obstructive pulmonary disease; primary care; electronic medical records; electronic health records; primary care; medical informatics; health informatics.

2.2 Introduction

Chronic obstructive pulmonary disease (COPD) is characterized by persistent airflow limitation and an enhanced chronic inflammatory airway response to noxious particles or gases such as tobacco smoke.[18] COPD is one of the leading causes of death worldwide,[19–22] with an estimated global prevalence of 64 million.[19] Studies project an increase in morbidity and mortality from COPD due to the aging demographic and the delayed effects of previous increases in smoking rates.[23] Despite its growing burden, COPD often remains incorrectly or under-diagnosed.[62,100] Primary care providers can play an important role in improving the management of patients with COPD. However, there is still a limited availability of population-wide data that can be used to build strategies for improvement of care, research and healthcare planning.

Previous work identifying people with and evaluating the burden of COPD have primarily been based on cross-sectional survey data and population cohorts.[22] Self-reported measures for COPD in surveys have been validated against clinical records and physician diagnosis with relatively high accuracy, but are limited in clinical information.[54–57] While population cohorts have been derived from health care claims from some administrative databases (particularly for populations with comprehensive health and drug coverage),[59] they are limited in the depth and details of patient clinical information because they are created to manage financial transactions rather than for research purposes or patient care.[63]

Electronic medical record (EMR) systems are a potential comprehensive source of information on the processes and outcomes of patient care. EMRs include documentation of clinical encounters that occur within the physician office, including the patient medical history, laboratory test results, prescriptions, specialist consultation letters, discharge summaries, and diagnostic tests. The increasing use of EMRs in primary care settings provides a source of detailed clinical information that is not readily available in survey data or administrative databases, and is being used to study COPD among populations in the UK[66,67], Sweden[101], Canada[39,65,102], and cross-nationally.[103–105] The objective of this study was to determine if patients with COPD could be accurately identified using data contained in an EMR within Ontario, Canada.

2.3 Methods

We conducted a validation study using retrospective chart abstraction to identify a reference cohort of individuals with physician-diagnosed COPD. This cohort was used as a reference standard to test a variety of EMR algorithms to identify patients with COPD. This study was approved by the institutional review board at Sunnybrook Health Sciences Centre, Toronto, Canada.

2.3.1 Data Source

Electronic Medical Record Administrative data Linked Database (EMRALD®) held at the Institute for Clinical Evaluative Sciences (ICES) was used as the data source to create the reference standard.[96] At the time of study, EMRALD® provided a sampling frame of 73,014 adult patients aged 20 or older as of December 31, 2010, and included all patient chart data entered in the EMR from 1986 to 2011. Patients in EMRALD® have been found to provide a good representation of the Ontario population.[99] Data are collected on a semi-annual basis. The inclusion criteria for patients were: to have a valid date of birth, a valid health insurance number, and have made at least one visit to any of the 83 participating physicians in the year preceding EMR data abstraction from the clinics. The physicians had to have used the EMR for at least two years so as to optimize the completeness of data.[99] These datasets were linked using unique encoded identifiers and analyzed at ICES.

A random sample of 5889 patients aged 35 and over was taken from the sampling frame using Structured Query Language (Microsoft SQL Server [2008]). Three trained chart abstractors performed manual chart reviews on all available patient charts to determine if patients had a diagnosis of COPD, classifying each encounter with the patient as indicating 'definite COPD' (i.e., diagnosis by the physician), 'possible COPD' (i.e., a prescription for a short-acting bronchodilator that could indicate an airway disease but not necessarily for COPD), 'COPD ruled out' (i.e. a negative test result or ruling out by the physician), or 'no mention of COPD'. Abstractors assessed the cumulative patient profile, each entry in the chart, which included diagnostic information such as pulmonary function test (PFT) results and prescriptions for COPD related medications including short-acting anticholinergic bronchodilators (ipratropium, combined ipratropium and salbutamol), and long-acting muscarinic antagonist (tiotropium). Inter- and intra-rater reliabilities of the chart abstractions were verified by double-abstraction of 10% of the charts and calculating kappa-scores. The study team re-reviewed patients' charts

which were marked as ‘possible’ or as ‘definite’ but had no COPD prescriptions in the medication field to verify the accuracy of the abstraction.

2.3.2 EMR algorithm development

The patients identified as ‘definite COPD’ after the chart abstraction review were used as the reference standard against which various EMR algorithms identifying patients with COPD were tested. Algorithms were developed from searching within EMR data components for terminology specific to COPD, including its acronyms, full spelling, and common misspellings. The cumulative patient profile (CPP) algorithm searched for evidence of terms that implied positive COPD diagnosis in the CPP (i.e. problem list and past medical history). The prescription algorithm searched the medication list of the EMR for COPD-specific medications including their generic and trade names within varying time intervals and if they were prescribed at any point in time versus being currently active prescriptions. Algorithms for billing codes searched for physician billing codes for COPD (‘chronic bronchitis’ (491), ‘emphysema’ (492), or ‘other COPD’ (496) within varying time frames. Finally, a search for the smoking status of the patient (current smoker, ex-smoker, non-smoker, unspecified) was determined by the most recent smoking history section of the cumulative patient profile.

2.3.3 Analysis

Algorithm performance was analyzed using the concepts of diagnostic test evaluation using the manual chart abstraction as the reference standard. We calculated the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), 95% confidence intervals (CI) (determined by using an exact method based on a binomial distribution), and prevalence of COPD for each of the algorithms using Microsoft SQL. All algorithms developed from individual EMR components (CPP, prescriptions, physician billings) were compared to assess how they impacted the sensitivity, specificity, PPV and NPV scores. Each algorithm’s diagnostic odds ratio, positive likelihood ratio (LR+), and negative likelihood ratio (LR-) were calculated for further assessment. Different variations of EMR components were combined to maximize each of the scores.

2.3.4 Code availability

The computational and statistical codes used for analysis are available from the corresponding author on request.

2.3.5 Data availability

The dataset used in this study is held securely in coded format at the Institute for Clinical Evaluative Sciences (ICES). Although data sharing agreements prohibit ICES from making the dataset publicly available, access may be granted to those who meet the conditions for confidential access.

2.4 Results

2.4.1 Reference standard

The abstracted cohort consisted of 364 patients with definite COPD out of a total of 5,889 patients, resulting in a prevalence of physician-diagnosed COPD of 6.2%. Compared to people in the reference cohort, those with COPD were older and had a higher proportion of males. They were also more likely to have smoking history recorded in their charts (70% compared to 61% in those without COPD), and to have documented PFT results (40% versus 5% in patients without COPD) (Table 2-1). Review of the charts of patients with COPD who were non-smokers revealed seven patients who were subjected to long-term second-hand smoke and five patients with a history of occupational or environmental exposure.

2.4.2 EMR algorithm validation

The algorithms tested for identifying patients with COPD in the EMR all had high specificity and NPV, but varied in their sensitivity and PPV (Table 2-2). An algorithm consisting of documentation in the CPP alone had a PPV of 95% but detected only slightly over half (56%) of the patients with COPD from the reference standard.

Algorithms using at least one COPD billing code (any of 491, 492 or 496) captured only about half of the patients with COPD and had a PPV of 61%. Algorithms that searched for at least two of any of the billing codes in the span of one year had a lower sensitivity of 28%, but a higher PPV at 87%. When looking at COPD medications, we found varying degrees of accuracy with tiotropium and ipratropium (or combinations) Algorithms searching for ipratropium (or ipratropium/salbutamol) prescriptions had a sensitivity of 13% and PPV of 75%, while searching for prescriptions of tiotropium resulted in a sensitivity of 51% and an excellent PPV of 99.5%. Combining all prescriptions increased the sensitivity slightly to 52% and had a PPV of 98%. A recorded history of being a current smoker or ex-smoker captured 28% and 30% of patients with

COPD respectively. However, using smoking history alone resulted in a very low PPV of 16 and 11%.

Algorithms using a combination of different EMR components (CPP, prescriptions, billing codes) had higher sensitivity than the individual components alone, while maintaining high scores for PPV, specificity and NPV. Our final algorithm optimizing PPV and sensitivity included COPD documentation in the CPP; a prescription for tiotropium at any time; or a prescription for ipratropium (or ipratropium/salbutamol) in conjunction with a COPD billing code at any time in the chart; or at least 3 COPD billing codes within one year. This algorithm resulted in 77% sensitivity and PPV of 94%, with the highest DOR of 966, high LR+ of 224 and modest LR- of 0.23.

An alternative algorithm could increase the sensitivity marginally by searching for COPD documentation in the CPP; any of the COPD-specific prescriptions; or at least 2 COPD physician billing codes within 1 year. This algorithm had a sensitivity of 79%, PPV of 87%, a very high DOR of 495, LR+ of 104 and LR- of 0.21, resulting in prevalence of 5.6% in the population compared to the 6.2% in the reference cohort.

Including a positive smoking history to either of the two optimized algorithms increased the sensitivity to a maximum of 90% but resulted in over 25% reduction in specificity and 75% reduction in and PPV.

2.4.3 Discordance analysis

Using the search algorithm that optimized PPV and sensitivity, there were 84 false negatives and 19 false positives. Of the 84 false negatives less than six (<8%) patients were not correctly identified with COPD because their primary care CPP phrasing met exclusion rules. Specifically, there was a query "?" or "possible" label next to the diagnosis of COPD in the CPP despite a definitive diagnosis in other parts of the patient record. Approximately a quarter of the patients had less than three COPD billing codes from their family physicians. Fifty-eight (65%) were not identified because of what appeared to be an incomplete primary care CPP, where there was no mention of COPD in the CPP despite a diagnosis and documentation in the body of the chart or in consultation notes from other physicians. All 85 patients did not have a prescription in their family physician's EMR for tiotropium, ipratropium (or ipratropium/salbutamol). Out of the 19 false positives, 11 (58%) had COPD listed in the CPP as a possible diagnosis, followed by

text not considered by our exclusion rules (e.g. “Asthma/COPD”), or it appeared that the CPPs were not updated as there was evidence in the chart that the diagnosis was only suspected or had been ruled out. Eight (42%) met the billing code criteria but had no further documentation in the charts indicative of COPD.

2.5 Discussion

We conducted a validation study that confirmed that an EMR algorithm could accurately identify patients with physician-diagnosed COPD using data components contained in primary care EMRs. Our final algorithm optimizing PPV and sensitivity searched for indication of COPD in the CPP; prescription for tiotropium at any time; prescription for ipratropium (or ipratropium/salbutamol) in conjunction with a COPD billing code; or at least 3 COPD physician-billing codes within one year. This validated algorithm could be used to accurately identify a cohort of patients with COPD in primary care to conduct future studies in COPD quality of care, clinical audit, prediction modeling and health care utilization patterns.

When compared to previously described COPD EMR algorithms from other jurisdictions,[39,65,66,102] our algorithm performed with the highest PPV published to date. A high PPV indicates a high proportion of positive results that are true positives, which is useful in identifying cohorts that actually have COPD. As seen in previous studies, there is a trade-off between accuracy and capture rate when selecting an algorithm. For instance, Cooke et al[58] described a COPD algorithm using administrative data with a high sensitivity of over 90% with lower PPV of 58%. With a different set of input variables in their model, this shifted to a moderate sensitivity of 71.9%, and improved PPV of 71.2%.[58] Similarly, using EMR data, Kadhim-Saleh et al[39] had algorithm results ranging from a lower sensitivity of 41% and higher PPV of 80%, to a higher sensitivity of 82.1% and lower PPV of 72.1%.[39] As these components often counterbalance each other, users of algorithms should evaluate the trade-offs and purpose of the algorithm they choose to apply in their research. Additional considerations include the implication of errors (e.g. false positives and false negatives), and the prevalence of the disease in the population (if it is rare or common). Sensitivity should be optimized in cases where it is important to minimize false negatives and detect as many cases as possible (e.g. disease surveillance, high risk associated with missed detection, public health education or preventive/early detection and intervention purposes). It was important for our algorithm to

achieve the highest PPV possible in order minimize the number of false positives in identifying future cohorts of patients that are correctly identified as having COPD. In doing so, it would improve the accuracy of the algorithm and ensure any analysis related to COPD in our database would reflect care specific to the disease of interest as much as possible. High accuracy of the algorithm was also indicated by the high DOR, which measures the algorithm's effectiveness, and high LR+, which assesses the performance of the algorithm in finding positive results.

There have been two other algorithms in the literature that use EMR data to identify patients with COPD. One algorithm (using the case definition of 'obstructive chronic bronchitis' (491.2), 'emphysema' (492), or 'chronic airway obstruction' (496) in the billing history or in the problem list; or tiotropium, ipratropium, or salbutamol and other drugs for obstructive airway disease listed under medication; with the exclusion of people under the age of 35 and those who fulfill only the medication criteria alone and also have asthma) that was applied in different clinics and regions across Canada,[39,65,102] showed varying sensitivity (41-82%), specificity (92-99%), PPV (37-80%), and NPV (88-98%) for the identification of COPD across sites. These varying results suggest that further studies are needed to understand how to best use EMR algorithms for diverse populations. An algorithm used in the UK[66] had access to a different set of EMR data components and codes than those used in this study, including those for spirometry or PFTs and was therefore not comparable to our study. Although PFT results could not be included in our algorithm, it would be possible to incorporate billing codes for spirometry by linking the EMR data with Ontario's administrative dataset in future studies.

We found that looking in the CPP alone or COPD billing codes alone yielded sub optimal sensitivity (<60%). This suggests that the documentation and billing patterns for COPD within primary care physicians in their EMRs is variable and/or incomplete. Searching for COPD prescriptions alone in the algorithm also had low sensitivity as not all patients with COPD are given prescriptions for tiotropium, ipratropium or combination of ipratropium/salbutamol by their family physician. Patients may have received other medications such as short-acting bronchodilators, but as these medications are not specific for COPD and are also given for other conditions (e.g. asthma or acute bronchitis) they were excluded from our algorithm.[65] Additionally, medication prescribed by specialists may be missing in the primary care EMR as the accuracy and completeness of the medication list in the EMR is dependent on individual family physicians to record them.

Our study shows that searching for billing codes alone or COPD medications alone misses many with COPD with a lower degree of accuracy than also searching the CPP. However, there are also challenges associated with distinguishing COPD from other respiratory conditions such as acute bronchitis or asthma.[60,106,107] These complexities are reflected in notations within the EMR entries and CPP (e.g. "?Asthma/COPD" [sic] in the CPP and problem list indicating possible but not ruled-out diagnosis of COPD), making it challenging to use automated text searching algorithms to identify the most up-to-date and relevant information. The inaccuracies recorded in the CPP highlight the need to improve recording of COPD diagnosis among primary care practice within EMRs.

Searching for COPD specific medications to identify patients with COPD also presented some challenges. In a previous study by Coleman et al,[65] inclusion of COPD medication (e.g. salbutamol) in their algorithm resulted in nearly half of the results being a misdiagnosis, as the medications included could also be used for acute bronchitis, chronic cough or asthma.[65] In consultation with respirologists, we reduced the list to 3 medications that were as specific as possible to COPD to limit the number of false positives. However, we still noted that tiotropium and ipratropium may both be used for severe cases or exacerbations of asthma.[108,109] There were also instances where patients were provided with samples or trials of drugs of tiotropium without a confirmed diagnosis of COPD to see if presenting symptoms improved. These resulted in a small number of false positive misclassifications. Furthermore, as medications are manually entered to the EMR and physicians may or may not utilize medication drop down lists, we may not have accounted for all misspellings and short-forms of the drug names, or prescriptions provided by other providers and specialists outside the primary care practice.

We did not include smoking history in our final chosen algorithms. Smoking remains a significant risk factor for COPD[1] and patients' smoking history can be captured in the EMR. As seen in Table 1, we found a higher proportion of EMR documented smoking history among patients with COPD compared to the whole study cohort (70% versus 61%). These rates of documentation are higher than a previous Swedish study where one-third of patients had information on smoking recorded in their records.[101] However, while smoking history could be helpful in supporting a positive diagnosis clinically and could increase the sensitivity, it was not included as a data component in the EMR algorithms due to the low PPV and lack of precision. When smoking status (current smoker or ex-smoker) was added as a factor in our top algorithms,

the sensitivity rose above 90%, but the specificity decreased to 72% and PPV to only 17% (see Table 2). This result is due to the fact that smoking status was not captured for everyone and a positive smoking history is not solely diagnostic of COPD.

PFTs are widely available and has been recommended for confirmation of COPD diagnosis.[18] However, we found that PFT results were recorded in the EMR for only 40% of the patients with COPD and 5% of patients without COPD, consistent with previous studies.[60,106] These low rates of PFTs could be because the PFT performed and the COPD diagnosis predates the start of the EMR record, or because a PFT was not done. With linkage to administrative data, it is possible to differentiate these possibilities and can be performed in future studies. In addition, PFTs that are performed outside of the clinic are often sent in via fax or scanned in, thus the results are not always captured in a text searchable format in the EMR. The limited availability and inconsistent formatting of the results did not allow for us to include PFT results in our EMR algorithm. These findings are similar to those found in Sweden, where only 29% of the primary healthcare centres had extractable PFT data due to lack of common structure for its documentation.[101] In a few cases where a computed tomography scan consistent with COPD was recorded, we accepted this as a definitive case of COPD. Our study highlights the need to standardize and automate the capture of diagnostic test results related to COPD.

Other considerations for this study include limitations to generalizability. Our study uses EMR data from primary care practice in a voluntary subset of the Ontario population using one type of EMR software within the study period. Despite this, patients in EMRALD® have similar characteristics to the general population in terms of presence of chronic diseases and co-morbid conditions.[99]

The literature on developing COPD algorithms show that there may be bias for diagnosis according to patients' sex, race, level of education, and level of severity of COPD resulting in under- or over-diagnosis.[110,111] These socioeconomic and demographic factors were not accounted for in this study, and we were unable to determine severity of COPD. While these issues are beyond the scope of this study, they would be important areas for future research and could be studied with a larger cohort of COPD patients and in conjunction with administrative data.

2.6 Conclusion

We conducted a validation study that confirmed that an EMR algorithm can accurately identify patients with physician-diagnosed COPD using data components contained in primary care EMRs. Our COPD cohort had characteristics consistent with those in the literature, suggesting good validity of our reference standard. Our findings indicate the importance of keeping the CPP up to date in primary care practice, which would improve the accuracy of EMR algorithms to identify patients with COPD. There is also a need to improve recording of diagnostic tests for COPD. Researchers and other users of EMR data should take caution and note the limitations of using billing codes alone or medication lists alone to identify patients with COPD.

As EMRs become increasingly used across jurisdictions, it presents many opportunities to study detailed clinical information on a broad population with COPD, including nationally and internationally.[101,103–105] This study shows that primary care EMR data can be a promising source of data to study populations in the community with COPD in Ontario the most populous province in Canada. Using EMR algorithms to identify patients with COPD has the potential to help study quality of care, appropriate use of pharmacological therapy, patient outcomes, health care utilization patterns, and clinical and economic consequences with the ultimate goal of improving patient care and outcomes.

2.7 Tables and figures

Table 2-1 Study cohort characteristics by COPD diagnosis derived from primary care electronic medical record chart abstraction.

	Total (*n*=5,889)	**Patients without COPD (*n*=5,525)**	**Patients with COPD (*n*=364)**
Mean age, years (SD)	56.3 (±13.5)	55.4 (±13.2)	68.6 (±11.5)
Age >65 years, *n* (%)	1467 (24.9)	1244 (22.5)	223 (61.2)
Female, *n* (%)	3319 (56.4)	3157 (57.1)	162 (44.5)
Smoking history recorded, *n* (%)	3599 (61.1)	3345 (60.5)	254 (69.8)
Current smoker	656 (18.2)	554 (16.6)	102 (40.2)
Previous smoker	1121 (31.1)	994 (29.7)	127 (50.0)
Non-smoker (including second-hand smoke and environmental/occupational exposure)	1822 (50.6)	1797 (53.7)	25 (9.8)
Not recorded	2290 (38.9)	2180 (39.5)	110 (30.2)
Pulmonary Function Test record in EMR, n (%)	430 (7.3)	283 (5.1)	147 (40.4)

COPD – chronic obstructive pulmonary disease; SD – standard deviation

Table 2-2 Test characteristics of various electronic medical record COPD algorithms when validated against an abstracted patient chart reference standard (n=5889, COPD prevalence=6.2%).

Algorithm	True positive (*n*)	True negative (*n*)	False positive (*n*)	False negative (*n*)	Sensitivity (95% CI)	Specificity (95% CI)	Positive predictive value (95% CI)	Negative predictive value (95% CI)	Positive likelihood ratio (95% CI)	Negative likelihood ratio (95% CI)	Diagnostic odds ratio (95% CI)
Cumulative Patient Profile in the EMR											
Problem list & past medical history	205	5514	11	159	56.3% (51.1-61.5)	99.8% (99.6-99.9)	94.9% (91.1-97.4)	97.2% (96.7-97.6)	282.9 (155.7-514.0)	0.44 (0.39-0.49)	646.3 (345.3-1209.6)
Physician billing codes for COPD (any of 'chronic bronchitis' [491], 'emphysema' [492] or 'other COPD' [496])											
≥1 billing code (ever)	188	5405	120	176	51.6% (46.4-56.9)	97.8% (97.4-98.2)	61.0% (55.3-66.5)	96.8% (96.4-97.3)	23.8 (19.4-29.1)	0.49 (0.44-0.55)	48.1 (36.6-63.3)
≥2 billing codes in 1 year	100	5510	15	264	27.5% (22.9-32.4)	99.7% (99.6-99.8)	87.0% (79.4-92.5)	95.4% (94.9-96.0)	101.2 (59.4-172.3)	0.73 (0.68-0.77)	139.1 (79.8-242.8)
Positive smoking history											
Current smoker	102	4971	554	262	28.0% (23.5-32.9)	90.0% (89.2-90.8)	15.5% (12.9-18.6)	95.0% (94.4-95.6)	2.8 (2.3-3.4)	0.80 (0.75-0.85)	3.5 (2.7-4.5)
Ex-smoker	118	4531	994	246	32.4% (27.6-37.5)	82.0% (81.0-83.0)	10.6% (8.9-12.6)	94.9% (94.2-95.5)	1.8 (1.5-2.1)	0.82 (0.76-0.89)	2.2 (1.7-2.8)
Medication prescriptions in the EMR											
Tiotropium or ipratropium (or ipratropium/ salbutamol)	198	5508	17	166	52.2% (46.9-51.4)	99.9% (99.8-100.0)	97.9% (94.8-99.4)	96.9% (96.5-97.4)	176.8 (109.0-286.8)	0.46 (0.41-0.52)	386.5 (230.0-649.3)
Tiotropium	186	5524	11	159	51.1% (45.8-56.3)	100.0% (99.9-100.0)	99.5% (97.1-100.0)	96.9% (96.4-97.3)	271.3 (149.1-493.5)	0.46 (0.41-0.51)	587.5 (313.4-1101.1)
Ipratropium or ipratropium/ salbutamol	47	5509	16	317	12.9% (9.6-16.8)	99.7% (99.5-99.8)	74.6% (62.1-84.7)	94.6% (93.9-95.1)	44.6 (25.5-77.8)	0.87 (0.84-0.91)	51.1 (28.6-91.0)
Combinations of cumulative patient profile, prescription and billing code algorithms											
CPP ***OR*** Tiotropium ***OR*** (ipratropium ***AND*** ≥1 billing code) ***OR*** ≥3 billing codes in 1 year	280	5506	19	84	76.9% (72.2-81.2)	99.7% (99.5-99.8)	93.6% (90.3-96.1)	98.5% (98.1-98.8)	223.7 (142.3-351.6)	0.23 (0.19-0.28)	966.0 (578.8-1612.1)
CPP ***OR*** Any COPD prescription ***OR*** ≥2 billing codes in 1 year	288	5483	42	76	79.1% (74.6-83.2)	99.2% (99.0-99.5)	87.3% (83.2-90.7)	98.6% (98.3-98.9)	104.1 (76.7-141.3)	0.21 (0.17-0.26)	494.7 (333.3-734.4)
Combination of cumulative patient profile, prescription, billing code algorithms, and positive smoking history (current or ex-smoker)											
CPP ***OR*** Tiotropium ***OR*** (ipratropium ***AND*** ≥1 billing code) ***OR*** ≥3 billing codes in 1 year ***OR*** positive smoking history	325	3969	1556	39	89.3% (85.6-92.3)	71.8% (70.6-73.0)	17.3 % (15.6-19.1)	99.0 % (98.7-99.3)	3.2 (3.0-3.4)	0.15 (0.11-0.20)	21.3 (15.2-29.8)
CPP ***OR*** Any COPD prescription ***OR*** ≥2 billing codes in 1 year ***OR*** positive smoking history	329	3955	1570	35	90.4% (86.9-93.2)	71.6% (70.4-72.8)	17.3% (15.6-19.1)	99.1% (98.8-99.4)	3.2 (3.0-3.4)	0.13 (0.10-0.18)	23.7 (16.6-33.7)

CI – confidence interval; COPD – chronic obstructive pulmonary disease; EMR – electronic medical record; SD – standard deviation

Chapter 3

Measuring cardiovascular quality in primary care using Canadian Cardiovascular Harmonization of National Guidelines Endeavour and EMR data in Ontario

The purpose of this chapter is to answer the question, "can EMRs be used to measure primary care physicians' adherence to clinical practice guidelines for patients with chronic diseases, specifically CVD?" To measure the quality of chronic disease management, quality indicators are required. The objective of this chapter was to assess if primary care physicians are adhering to recommended clinical practice guidelines for cardiovascular disease management based on a set of quality indicators developed from the Canadian Cardiovascular Harmonized National Guideline Endeavour (C-CHANGE) recommendations

A modified version of Chapter 3 was published in the Canadian Journal of Cardiology Open as an original research paper (Figure 3-1).

Original Article

Measuring Cardiovascular Quality in Primary Care Using Canadian Cardiovascular Harmonization of National Guidelines Endeavour and Electronic Medical Record Data in Ontario

Figure 3-1 Lee TM, Tobe SW, Butt DA, et al. Measuring Cardiovascular Quality in Primary Care Using Canadian Cardiovascular Harmonization of National Guidelines Endeavour and Electronic Medical Record Data in Ontario. *CJC Open*. 2019;1(1):1-9. doi:10.1016/j.cjco.2018.11.003

3.1 Abstract

Background: This project uses electronic medical record (EMR) data to assess performance by family physicians (FP) in the screening for, diagnosis, and management of cardiovascular disease (CVD) and risk factors against national harmonized guidelines by the Canadian Cardiovascular Harmonization of National Guidelines Endeavour (C-CHANGE).

Methods: A retrospective cohort study using the Electronic Medical Record Administrative data Linked Database (EMRALD®) was conducted. A set of quality indicators (QI) were developed based on 2014 C-CHANGE guidelines. Twenty-three readily measurable QIs were used to measure performance in the screening for and management of CVD; and to identify gaps in performance.

Results: Our study population consisted of 324 Ontario FP and 284,959 patients. We assessed 23 of the 74 recommendations. There was variance in rates of adherence to QIs related to screening rates for CVD. Highest adherence to C-CHANGE guidelines were related to routine laboratory testing for patients with hypertension and prescription of antihypertensive therapies. Lowest adherence to the guidelines were seen in administration of oral glucose tolerance tests for assessing pre-diabetic patients (4.4%).

Conclusion: FP EMR data can be used to measure adherence to a third of the C-CHANGE recommendations. There are varying levels of adherence among the measurable C-CHANGE recommendations, and there is room for improvement in quality of primary care management of CVD in Ontario. There is potential to use EMR data to assess changes to CVD management in FP practice using C-CHANGE guidelines when recommendations are quantifiable and measurable.

3.2 Introduction

Multiple chronic conditions and cardiovascular disease (CVD) cause high burden on the Canadian health care system. Four in five Canadians have at least one risk factor for CVD, which is the leading cause of preventable death and disability nationwide.[17] As the number of Canadians with risk factors for CVD increases, family physicians (FPs) have an increasingly important role and responsibility in its management. In 2014, the Canadian Cardiovascular Harmonized National Guidelines Endeavour (C-CHANGE) updated their guidelines for prevention and management of CVD, which assists health care practitioners by synthesizing the best available evidence.[112,113] The C-CHANGE Guidelines from 2014[113] are composed of 74 key recommendations selected from more than 400 recommendations sourced from eight different guideline groups.[4-11] Widespread adoption of C-CHANGE guidelines among FPs has the potential to improve quality of cardiovascular care. However, there is little information on how real-world practice reflects the recommendations from C-CHANGE.

In Ontario, over 80% of FPs have adopted electronic medical records (EMR) as of the most recent National Physician Survey.[122] The increasing uptake of EMR in primary care practices provide opportunities to use routinely collected clinical data to evaluate quality of clinical care. The objective of our study was to determine the feasibility and to develop methods to assess quality of care related to the screening and management of CVD in primary care in Ontario by using EMR data, and to obtain baseline measures on how closely FPs practices aligned with C-CHANGE guideline recommendations at the time of release.

3.3 Methods

3.3.1 Data source

We conducted a retrospective cross-sectional study of patients enrolled in ('rostered' to) FPs' practices that contribute data to the Electronic Medical Record Administrative data Linked Database (EMRALD®) held at the Institute for Clinical Evaluative Sciences (ICES).[96,98] Ontario has a publicly-funded healthcare system and individuals have a designated FP to whom they are 'rostered'. EMRALD® includes all patient chart data entered in the EMR dating back from the time the FP started using Telus Practice Solutions® EMR. EMRALD® contains longitudinal data as far back as 1986.

3.3.2 Cohort

The study cohort was derived from EMRALD® and matched both the physician and patient inclusion and exclusion criteria. To be eligible, the physician had to be using the EMR for at least eighteen months prior to data collection to meet optimal levels of data quality and completeness.[96,98] Patients had to have a valid date of birth, a valid health insurance number, be rostered to the family physician, and made a visit to a participating EMRALD® physician in the 36 months preceding data extraction. The data extraction took place between November 2013 and October 2014.

To evaluate the generalizability of our results, we compared the study physicians enrolled in EMRALD® to all physicians in Ontario in terms of their sex, age, practice location, place of medical training, primary care model and practice duration. We compared patients rostered to the study physicians to all patients in Ontario and all patients who were rostered to a FP in Ontario. We compared the groups and described population trends and differences. We analyzed coded data using SAS v9.2 and Microsoft Structured Query Language (SQL) 2012.

These datasets were de-identified and linked using unique encoded identifiers and analyzed at the Institute for Clinical Evaluative Sciences (ICES). Ethics approval was obtained from the institutional review board at Sunnybrook Health Sciences Centre, Toronto.

3.3.3 Quality indicator development

Recommendations from C-CHANGE clinical guidelines were developed into quality indicators (QI) using Kötter's iterative development process used to modify clinical guidelines into measurable QIs.[123] All 74 recommendations from the C-CHANGE guideline were reviewed by the authors to assess measurability within the EMRALD® database. A numerator, denominator, exclusion criteria and time frame (look back period in which the recommendation was met) were defined for each measurable recommendation. Measurability required availability of relevant clinical information in EMRALD®, feasibility to capture the numerator and denominator in structured or semi-structured fields, and consistency of data recording among FPs. QIs requiring search of unstructured free-text sources were excluded from the scope of this study.

Unless a specific timeline was specified in the wording of the recommendation, the timeframe and look-back period for searching the record was 18-months for all prescription indicators; 12-

months for the most recent blood pressure (BP) measurements; 18-months for the most recent HbA1c results; 3-years for lipid profile tests and liver enzyme test results; and all-time for indicators involving other tests. When searching for body mass index (BMI) in adults, the last recorded BMI was used with no time restriction. For children, the most recent measurement of BMI from the previous three years were considered.

Age-based recommendations (i.e. tests to be ordered when a patient is older than a certain age) included an additional 12-month buffer period to ensure subjects had adequate time to receive the care upon reaching the defined age. Preliminary data were reviewed by the investigators to ensure that the QIs measured captured the clinical relevance and intention of the recommendation as closely as possible.

Microsoft SQL was used to search EMRALD® for inclusion and exclusion terminologies in the database (the patient medical history, demographic information, laboratory test results, medication list, problem list and anthropometric measures). Previously developed EMR algorithms were used to identify the presence of hypertension[124], diabetes[125,126], ischemic heart disease or coronary artery disease (CAD)[127], congestive heart failure, atrial fibrillation[128], stroke[129] and chronic kidney disease (CKD)[124]. Where macrovascular target organ damage was called for, we included CAD and stroke. Where target organ damage was called for, we were able to include CAD, stroke and CKD as we were unable to measure microvascular injuries or complications.

Measurable QIs were assessed for all eligible patients, with look-back periods counting back from the date of last data collection. Descriptive statistics of the study population's demographic and disease characteristics were calculated. The outcomes of interest were the unadjusted proportions of patients receiving guideline adherent care, calculated for each measurable QI.

3.4 Results

3.4.1 Population characteristics

There were 324 physicians who met the study inclusion criteria. Compared to the average Ontario FP, the study FPs were more likely to be female, younger, rurally-represented and medically trained in Canada (Table **3-1**). Together, the study physicians had 284,959 patients rostered to their care. The age distribution, number of aggregated diagnosis groups (ADG)[130,131]

(a co-morbidity measure), prevalence of chronic conditions were comparable between EMRALD® patients and the average rostered patient in Ontario (Table 3-2). Patients' medical history had been on the EMR for an average of 4.9 years with a standard deviation (SD) of ±2.8 years. Participating FPs had been using *PS Suite*® EMR for an average of 6.1 years (SD ±3.4 years).

3.4.2 QI measurement

Of 74 C-CHANGE QIs, 23 were deemed measurable. QIs were reported according to their order of appearance in the original guideline (see Figure 3-2) and are described in Appendix B. Four QIs were outcome-based and 19 QIs were process-based. Data in the EMR were not sufficient to accurately measure the remaining 51 recommendations due to data availability, high variability in recording among FPs, limited data standards, or subjectivity in interpretation of the recommendation.

High adherence was seen in QIs related to hypertensive patients. Over 90% of patients with hypertension got routine laboratory tests completed for blood chemistry potassium, sodium, creatinine and lipid profile (QI 9a-c, e), but lower adherence rates were seen in other indicated laboratory tests of fasting plasma glucose (FPG) (QI 9d, 56.9%), and 12-lead electrocardiography (ECG) (QI 9f, 55.6%). High adherence was seen for QIs related to receiving appropriate antihypertensive medication (QI 20, 73.2%) including for patients who also had CAD (QI 13, 81.5%; QI 23, 72.5%).

Lipid tests were done in 79.8% of men over 40 years old and women over 50 years old with no look-back time limit, and when limited to the past 3 years the proportion of patients tested was 68.7% (QI 7). This proportion was higher at 91.9% in patients with hypertension (QI 9e).

Out of all adults (n=233,081), 67.6% had a height recorded; 77.4% had their weight recorded; 67.3% had both height and weight recorded separately in their medical history; and 67.1% had a BMI calculated in the EMR and recorded in their medical history. Only 2.2% of the population had a waist circumference recorded. Children between the ages of 2 and 17 had their BMI recorded in the EMR in the past 3 years in 59.7% of the cases (QI 3). Smoking status was recorded for 61.0% of adults (QI 8), of which 18.8% were current smokers, 26.2% former smokers, and 54.9% never smoked.

The highest outcome-based indicator was the percentage of patients with diabetes whose last HbA1c reading was on target at less than 7.0% (QI 11, 59.7%). The three other outcome-based indicators were low. These consist of adults with a healthy BMI (QI 2, 34.1%); patients reaching HbA1c targets of less than 6.5% (QI 12, 39.4%); and patients with diabetes whose most recently recorded BP readings were on target at less than 130/80 (QI 14, 37.9%).

Patients who were overweight or obese (BMI > 25) represented 64.1% of the adult study population. Out of these patients, 63.0% received a liver enzyme test in the last 3 years (QI 10). When narrowed down to only patients who were classified as 'overweight' (BMI between 25 and 30), liver enzyme tests were completed for 59.9% of patients, compared to 66.5% of patients classified as 'obese' with a BMI over 30.

The lowest QI adherence rates were seen for two related recommendations, QIs 5 and 6: screening for impaired glucose tolerance or diabetes using 2-hour plasma glucose (2hPG) testing for patients who have plasma HbA1c results of 6.0 to 6.4% or 5.5 or 5.9%, respectively. We found that 2hPG tests were performed in these patients in 9.4% (QI 5), and 4.4% (QI 6) of the time, respectively.

3.5 Discussion

Our retrospective cross-sectional study using primary care EMR data in Ontario provides baseline measures and practice-based perspective on how CVD is screened, tested, and managed among FPs in Ontario at the time of study. The EMRALD® population is similar to that of the entire province, indicating generalizability. Our data shows a wide variation in practice with some areas of high concordance to guidelines but also substantial gaps in management of CVD. This is consistent with previous research that highlights gaps in treatment and management of vascular risk factors, particularly for patients with comorbidities such as diabetes.[25-28] While most studies focus on one area of vascular management or adherence to specific treatment type[29-31], our QIs provide insights on multiple aspects of CVD and can give guidance on what areas of vascular management have wider gaps than others.[136]

Only 23 of the 74, 2014 C-CHANGE guidelines recommendations could be developed into QIs. Most wording of the recommendations had not been developed considering the feasibility of measuring it as a QI. The way in which data is recorded into EMRs by FPs (i.e., free-text) limits

the measurability. For example, the guideline recommended that patients with hypertension should have their left ventricular ejection fraction (LVEF) measured by echocardiogram or nuclear imaging. Upon searching for the text related to LVEF in the record, we found 14,394 out of 48,956 patients with hypertension (29.4%) had 'LVEF' or 'echo' in their charts. Due to non-uniform use of terminology in the EMR, we were not confident in the measurability of this QI and omitted it.

Risk factors associated with patient ethnicity and race were not distinguished in our calculation for QIs which included them in the denominator. Waist circumference measurements in the assessment of healthy weight were omitted due to the low recording of waist circumference (5,125 out of 233,081 adult patients, 2.2%), and QI 1("height, weight and waist circumference should be measured and BMI calculated for all adults") focused instead on BMI in adults being recorded.

Urinalysis was recommended as one of the routine tests to be completed for QI 9 but was excluded in the modified QI. Urinalysis is not well recorded in the EMR due to how urine dip test or urinalysis is performed in the clinic and recorded in the EMR. Only 324 out of 48,965 (<1%) adult patients with hypertension had a record of urinalysis in the structured laboratory test portion of the EMR.

Sixteen recommendations related to patient diet, lifestyle and physical exercise were omitted as they were not routinely recorded in the EMR in a structured or semi-structured fashion. This study demonstrates the potential to provide feedback to guideline developers on what is needed to allow guideline recommendations to become measurable as QIs. Furthermore, the limitations of measurability may be of interest to EMR providers and developers of EMR data standards. These limitations highlight opportunities to improve data standardization through data structure or user guidance. Standardized data and measurability of QIs are necessary for monitoring and continuously improving quality of care.

Several of the highest adherence indicators were related to the provision of appropriate antihypertensive medication for patients with comorbidities. This data is consistent with the awareness treatment and control of hypertension in Canada.[139] An example of how the wording of a recommendation could be adapted and defined further to accommodate a QI is the lipid test (QI 7) which did not specify how frequently the test should be done. While lipids had been done

at some point, the rate in a more constrained time period was much less. Reassuringly though, among patients with hypertension, the rates of lipid testing were much higher (QI 9e, 91.9%) suggesting that clinicians were responding to perceived higher risk in these patients.

The finding that statin use among patients with diabetes over the age of 40 was 58.8% (QI 18) could indicate a significant treatment gap. However, this specific recommendation did not indicate if a statin should be used if their cholesterol is higher than a specific threshold. We found a low rate of antiplatelets for patients with CAD (QI 17, 43.4%). This may be reflective of the over-the-counter availability of acetylsalicylic acid (ASA), and consequent inadequate documentation of ASA use in the EMR. The majority of the outcome indicators were lower than 40%. Of concern, only 37.9% of patients with diabetes had a most recent BP measurement that was less than 130/80mmHg (QI 14). Furthermore, the majority of the adult population was overweight or obese. Only 34.1% of patients' BMI were in the 'normal' range of 18.5-24.9 (QI 2), consistent with the literature.[140,141]

3.5.1 Limitations

Modifying practice guidelines to measurable QIs requires specific and quantified actions to be defined, and for whom they should be taken.[142] As such, not every recommendation could be measured in the EMR. Due to each recommendation criteria, the denominator size is different in each QI and a common composite score applicable to everyone in the population could not be developed.

The interpretation of QI adherence rates should consider the context of the recommendation. The lowest QIs were related to 2hPG oral glucose tolerance test (OGTT) (QI 5 and 6), a time consuming and costly, but more sensitive diagnostic test for diabetes for certain patient groups[34-41]. For the A1c range of 5.5-6.0% (QI 6), the evidentiary base to conduct a 2hPG test is limited. We would suggest a review of this recommendation and its public health benefit as the tests are seldom being done in family practice. We found that with an ambiguous result suggesting pre-diabetes, that physicians were re-ordering HbA1c or FPG tests instead of ordering the 2hPG.

Overall, pharmacologic therapy QIs showed higher adherence. For the recommendations that specify first-line and subsequent second-line or combination therapies, we presented the proportion of patients who had any of (QI 20) or two (QI 21) of the indicated drug therapies. It was not possible to precisely determine if two prescriptions provided in the same timeframe in

the patient's record meant that they were being taken simultaneously for combination therapy, or if the physician prescribed a new drug without documenting the discontinuation of the previous drug. Additional work is required to fully assess the chronological sequencing of pharmacotherapy patterns.

This work was only performed on a convenience sample of FPs in Ontario. Findings may not be generalizable to the rest of Canada but can be used as a point of comparison for other studies. Similarly, the results reflect practice patterns as of the time of guideline release and may not be reflective of current practice. However, the results provide a baseline measure with which different time periods can be compared to identify changes in adherence and practice over time as well as to identify the gaps in care and areas that are most in need of improvement.

3.6 Conclusion

This project is a preliminary demonstration showing feasibility to measure FP performance based on C-CHANGE and EMR data. Based on the study results, it will be possible to use EMR data to identify further patterns of care for the diagnosis and management of CVDs and identify factors that impact clinical practice. This project also demonstrates that QI data has the potential to be used to feedback to guidelines groups on the wording of recommendations and the level of adherence when assessing a recommendation's significance or practicality. The value of the QI may suffer from variations in collection and recording of EMR data. This study should be able to help guidelines developers provide more implementable and measurable recommendations that better lend themselves to measurement and continuous quality improvement. This baseline assessment of FP practice performance can be compared prospectively for evaluation of different interventions and models of care on CVD management. The study demonstrates that databases like EMRALD® can be used to track changes in performance, patient adherence and improvements to patient outcomes.

3.7 Tables and figures

Table 3-1 Generalizability of study physicians from the Electronic Medical Record Administrative-data Linked Database.

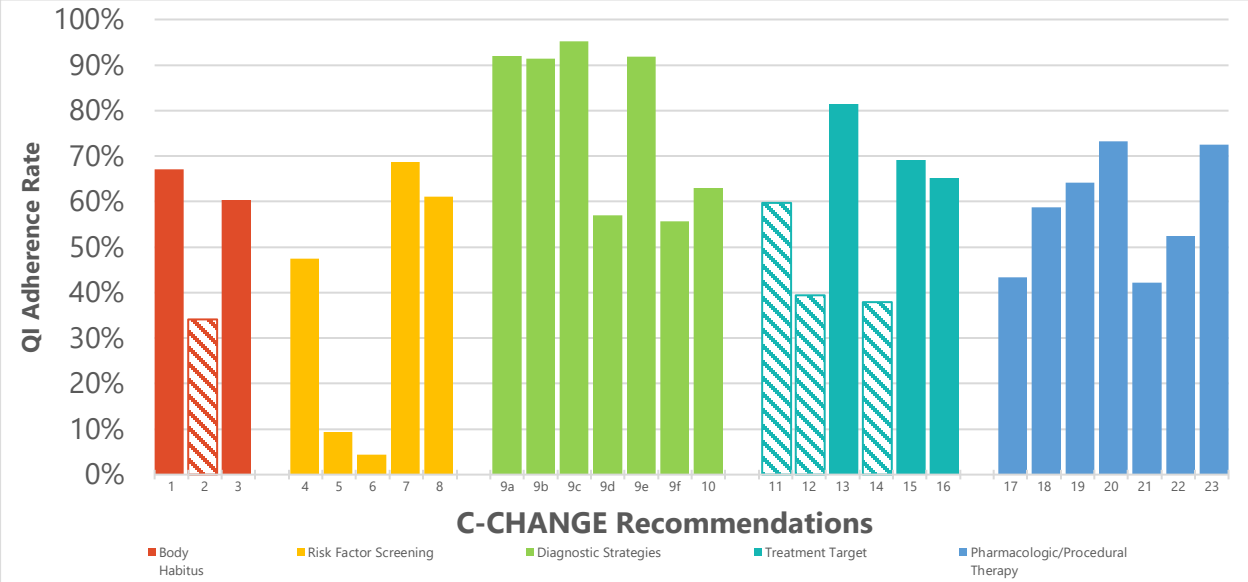
	All Ontario Physicians, March 31, 2014		**EMRALD® Cohort Physicians, March 31, 2014**	
	n	%	n	%
Total	8 219	100	324	100
Sex				
Female	3 621	44.1	180	55.6
Male	4 598	56.0	144	44.4
Age Group (years)				
1: <35	843	10.3	55	17.0
2: 35-44	1 667	20.3	106	32.7
3: 45-54	2 342	28.5	81	25.0
4: 55-79	3 367	41.0	82	25.3
Rurality				
Rural	388	4.7	34	10.5
Suburban	1 192	14.5	47	14.5
Urban	6 639	80.8	243	75.0
Medical Training Location				
Canada	5 722	69.6	294	90.7
International (including US)	2 497	30.4	30	9.3
≥25% bills from ED				
No	7 998	97.3	302	93.2
Yes	221	2.7	22	6.8
Primary Care Reform Model				
FHG or FHN	2 605	31.7	27	8.3
FHO	3 773	45.9	286	88.3
No model	1 343	16.3	0	0
Other	498	6.1	11	3.4
	Mean	**SD**	**Mean**	**SD**
Age as of March 31, 2014	51.2	11.8	46.1	10.8
Years in Practice	17.7	10.4	15.7	9.6
Years Since Graduation	25.2	12.3	19.8	11.3

ED – Emergency Department; FHG – Family Health Group; FHN – Family Health Network; FHO – Family Health Organization; SD – Standard deviation

Table 3-2 Descriptive characteristics of EMRALD® patient population compared with all patients in Ontario

	All Ontario patients, March 31, 2014		Rostered patients*, March 31, 2014		EMRALD® rostered Patients, March 31, 2014	
	N	%	N	%	N	%
Total	14 460 864	100	10 415 942	100	284 959	100
Sex						
F	7 355 447	50.9	5 463 075	52.5	158 049	55.5
M	7 105 417	49.1	4 952 867	47.6	126 910	44.5
Age Group (years)						
0-17	2 921 606	20.2	1 814 188	17.4	49 412	17.3
18-29	2 376 105	16.4	1 577 711	15.2	37 250	13.1
30-44	2 991 737	20.7	2 082 918	20.0	62 168	21.8
45-64	4 004 426	27.7	3 146 848	30.2	85 345	30.0
65-84	1 879 226	13.0	1 560 857	15.0	44 278	15.5
85+	287 764	2.0	233 420	2.2	6 506	2.3
Income Quintile						
1 (lowest)	2 678 464	18.5	1 790 531	17.2	48 522	17.0
2	2 743 264	19.0	1 982 573	19.0	48 969	17.2
3	2 837 651	19.6	2 110 409	20.3	52 400	18.4
4	3 051 515	21.1	2 309 165	22.2	60 514	21.2
5 (highest)	2 873 671	19.9	2 165 980	20.8	72 380	25.4
Missing	276 299	1.9	57 284	0.6	2 174	0.8
Rurality						
Missing	60 686	0.4	6 747	0.1	154	0.1
Non-rural area	12 820 125	88.7	9 221 469	88.5	226 856	79.6
Rural area	1 580 053	10.9	1 187 726	11.4	57 949	20.3
Number of Aggregated Diagnosis Groups (ADGs)						
1: 0 ADGs	1 313 256	9.1	725 231	7.9	14 456	5.1
2: 1-4 ADGs	6 441 104	44.5	4 879 393	46.9	145 403	51.0
3: 5-9 ADGs	4 765 921	33.0	3 908 790	37.5	102 827	36.1
4: 10+ ADGs	1 024 037	7.1	859 854	8.3	20 985	7.4
Missing data	916 546	6.3	42 674	0.4	1 288	0.5
Presence of condition						
Previous AMI	174 801	1.2	148 780	1.4	3 933	1.4
Asthma	1 990 635	13.8	1 571 629	15.1	39 356	13.8
CHF	207 357	1.4	174 620	1.7	4 963	1.7
COPD	835 575	5.8	704 907	6.8	19 173	6.7
Diabetes	1 305 025	9.0	1 109 386	10.7	26 481	9.3
Hypertension	2 887 490	20.0	2 468 841	23.7	61 488	21.6
Mental Health	2 536 179	17.5	2 076 262	19.9	58 951	20.7
Any chronic condition	6 450 553	44.6	5 295 718	50.8	140 053	49.2

**Rostered to a family physician as the primary responsible physician.*



Note: Striped quality indicators (QI 2, 11, 12, 14) indicate outcome-based indicators. The remaining indicators are process-based indicators.

Body Habitus

1. **% of adults with a body mass index (BMI) recorded [Lookback: All time]** Height, weight and waist circumference should be measured and BMI calculated for all adults.
2. *** % of adults with BMI between 18.5 and 24.9 [Lookback: All time]** Maintenance of a healthy body weight (BMI 18.5 to 24.9 kg/m$_2$, and waist circumference less than 102 cm for men and less than 88 cm for women) is recommended for non-hypertensive individuals to prevent hypertension and for hypertensive patients to reduce blood pressure. All overweight hypertensive individuals should be advised to lose weight.
3. **% of patients 2-17 years with BMI in the EMR [Lookback: 3 years]** Measuring body mass index (BMI = weight[kg]/height[m]$_2$) in children aged two to seventeen years.

Risk Factor Screening

4. **% of patients ≥ 41 years and no diabetes, with an FPG or HbA1c test in the past 3 years [Lookback: 3 years]** Screening for diabetes using FPG and/or A1c should be performed every 3 years in individuals ≥ 40 years of age or at high risk using a risk calculator. More frequent and/or earlier testing with either FPG and/or A1c or 2hPG in a 75 g OGTT should be considered in those at very high risk using a risk calculator or in people with additional risk factors for diabetes.
5. **% of patients ≥ 18 with FPG 6.1-6.9 and/or HbA1c 6.0%-6.4%, and a 2hPG test [Lookback: All time]** Testing with 2hPG in a 75 g OGTT should be undertaken in individuals with FPG 6.1-6.9 mmol/L and/or A1c 6.0%-6.4% in order to identify individuals with IGT or diabetes.
6. **% of patients ≥ 18 with FPG 5.6-6.0 and/or HbA1c 5.5%-5.9%, and a 2hPG test [Lookback: All time]** Testing with 2hPG in a 75 g OGTT may be undertaken in individuals with FPG 5.6-6.0 mmol/L and/or A1c 5.5%-5.9% and ≥ 1 risk factor(s) in order to identify individuals with IGT or diabetes.
7. % of male and ≥ 41 years or female ≥ 51 years or have diabetes mellitus, hypertension, CKD, currently smoke or are overweight, who have a lipid test [Lookback: 3 years] Screening of plasma lipids is recommended in adult men > 40 and women > 50 years of age or postmenopausal. Screen lipids at any age for: smoking, diabetes, hypertension, overweight, rheumatoid arthritis, systemic lupus erythematosis, psoriatic arthritis, ankylosing spondylitis, inflammatory bowel disease, chronic obstructive pulmonary disease, chronic HIV infection, CKD, abdominal aneurysm and erectile dysfunction. Consider screening individuals of First Nations or South Asian ancestry at an earlier age.
8. **% of adult patients with smoking status recorded in the EMR [Lookback: All time]** All patients/clients should be asked if they use tobacco and should have their tobacco use status documented on a regular basis. All physicians, nurses and other health care workers should strongly advise all patients who smoke to quit and provide brief advice.

Diagnostic Strategies

9. a. % of patients with hypertension, with a test for potassium; b. % of patients with hypertension with a test for sodium; c. % of patients with hypertension with a test for creatinine; d. % of patients with hypertension, with a test for FBG; e. % of patients with hypertension with lipid profile test; f. % of patients with hypertension with a test for ECG [Lookback: all time] Hypertension-Routine laboratory tests that should be performed for the investigation of all patients with hypertension include: urinalysis; blood chemistry ([9a] potassium, [9b] sodium and [9c] creatinine); (9d) fasting blood glucose; (9e) fasting serum total cholesterol and high density lipoprotein cholesterol, low density lipoprotein cholesterol and triglycerides; and standard (9f) 12-lead electrocardiography
10. **% of patients with a BMI ≥ 25.0, with a liver test [Lookback: 3 years]** Additional investigations, such as liver enzyme tests, urinalysis and sleep studies (when appropriate), to screen for and exclude other common overweight/obesity-related health problems.

Treatment Targets

11. *** % of patients with diabetes mellitus, with an HbA1c ≤ 7.0% [Lookback: 18 months]** Therapy in most individuals with type 1 or type 2 diabetes should be targeted to achieve an A1c ≤ 7.0% in order to reduce the risk of microvascular and, if implemented early in the course of disease, macrovascular complications.
12. *** % of patients with diabetes mellitus, with an HbA1c ≤ 6.5% [Lookback: 18 months]** An A1c ≤ 6.5% may be targeted in some patients with type 2 diabetes to further lower the risk of nephropathy and retinopathy, but this must be balanced against the risk of hypoglycemia.
13. % of patients with CAD or stroke and an average systolic BP ≥ 140 in the last year with antihypertensive therapy [Lookback: 18 months] Antihypertensive therapy should be strongly considered if systolic blood pressure readings average 140 mmHg or higher in the presence of macrovascular target organ damage.
14. *** % of patients with diabetes with most recent BP < 130/80 [Lookback: 1 year]** Persons with diabetes mellitus should be treated to attain systolic blood pressures of less than 130 mmHg and diastolic blood pressures of less than 80 mmHg. (These target blood pressure levels are the same as the blood pressure treatment thresholds.)
15. % of hypertensive patients with CAD or stroke with an average diastolic BP > 90 over the past 12 months, and on antihypertensive therapy [Lookback: 18 months] Antihypertensive therapy should be strongly considered if diastolic blood pressure readings average 90 mmHg or higher in the presence of macrovascular target organ damage or other independent cardiovascular risk factors.
16. % of patients ≥ 80 years with NO diabetes, CAD or stroke and an average systolic BP ≥ 160, and on antihypertensive therapies [Lookback: 18 months] In the very elderly (age 80 years and older), who do not have diabetes or target organ damage, the SBP threshold for initiating drug therapy is ≥ 160 mmHg and the SBP target is <150 mmHg.

Pharmacologic/Procedural Therapy

17. **% of patients with CAD and a prescription for anti-platelet agents [Lookback: 18 months]** Patients with documented coronary artery disease, in the absence of specific contraindications or documented intolerance, should be treated with anti-platelet agents; for patients with a history of chronic stable angina, remote PCI, or CABG, ASA (75 mg PO to 162 mg) PO daily indefinitely
18. **% of patients ≥ 40 years with diabetes and a prescription for statin therapy [Lookback: 18 months]** Statin therapy should be used to reduce cardiovascular risk in adults with type 1 or type 2 diabetes with any of the following features: Age ≥40 years
19. **% of patients ≥ 55 years with diabetes and a prescription for ACE inhibitors or ARBs [Lookback: 18 months]** ACE inhibitor or ARB, at doses that have demonstrated vascular protection, should be used to reduce cardiovascular risk in adults with type 1 or type 2 diabetes with any of the following: Age ≥ 55 years
20. % of patients with hypertension and a prescription for at least one of these kinds of drugs for thiazide diuretics; β-blockers; ACE inhibitors; CCBs or ARBs [Lookback: 18 months] Initial therapy should consist of monotherapy with a thiazide diuretic; a β-blocker (in patients younger than 60 years); an ACE inhibitor (in nonblack patients); a long-acting CCB; or an ARB. If there are adverse effects, another drug from this group should be substituted. Hypokalemia should be avoided in patients treated with thiazide diuretic monotherapy.
21. % of patients with hypertension with a most recent BP above target (BP Target ≤ 140/90 if patient < 80 years, BP Target ≤ 150/90 if patient ≥ 80 years, BP Target ≤ 130/80 if patient = diabetes mellitus) and a prescription for at least two first line anti-hypertensive agents [Lookback: 18 months] Combination therapy using two first-line agents may also be considered as initial treatment of hypertension if systolic blood pressure is 20 mmHg above target or if diastolic blood pressure is 10 mmHg above target.
22. **% of patients with CAD, diabetes mellitus, hypertension or CKD and a prescription for ACE or ARBs [Lookback: 18 months]** For persons with cardiovascular or kidney disease, including microalbuminuria or with cardiovascular risk factors in addition to diabetes and hypertension, an ACE inhibitor or an ARB is recommended as initial therapy.
23. **% of patients with hypertension and CAD and a prescription for ACE or ARBs [Lookback: 18 months]** An ACE inhibitor or ARB is recommended for most patients with hypertension and coronary artery disease

* denotes the QI is an outcome-based indicator (QI 2, 11, 12, 14). The remaining indicators are process-based indicators.

Figure 3-2 Adherence to C-CHANGE Quality Indicators (QI) in the EMRALD® population

Chapter 4

Measuring Chronic Obstructive Pulmonary Disease Quality Indicators within Primary Care Electronic Medical Records in Ontario, Canada

The purpose of this chapter is to answer the question, "can EMRs be used to measure COPD quality indicators in primary care?" Unlike Chapter 3 where quality indicators were developed from clinical guideline recommendations for cardiovascular health, this chapter looked at existing quality indicators for COPD. Chapter 4 sets out to use EMR data to assess primary care physicians' performance in COPD management.

The objectives of this chapter are to:

1. Assess whether quality indicators for chronic obstructive pulmonary disease (COPD) can be measured using primary care electronic medical records

2. Assess whether primary care practices are adhering to COPD quality indicators in Ontario.

4.1 Abstract

Background: The majority of patients with chronic obstructive pulmonary disease (COPD) are first diagnosed and treated in primary care. Best practice standards have been developed, but quality of care for COPD in this setting is uncertain. We sought to determine if it was possible to assess the quality of COPD management in primary care settings in Ontario using primary care electronic medical records (EMRs).

Methods: We conducted a cross-sectional study using EMR data from the Electronic Medical Record Administrative data Linked Database (EMRALD®) in Ontario, Canada, to assess COPD management by family physicians (FPs). We identified patients with COPD using a validated case-definition. Thirty-three COPD quality indicators were assessed for measurability by review of structured or semi-structured fields of the patients' EMRs. Eleven of these quality indicators were analyzed at the population-level, calculating the proportion and 95% confidence intervals (CIs) of patients meeting the quality indicator criteria. Performance of quality indicators were then aggregated at the physician-level, to assess the variability of rates across FPs' practices.

Results: We included 6995 patients with COPD who were rostered to 247 FPs. Recording of smoking history (85.1%, 95% CI [84.3%, 85.9%]) and prescription of long-acting bronchodilators (76.9%, 95% CI [75.9%, 77.9%]) were the most commonly achieved quality indicators. We found infrequent utilization of oxygen therapy (8.1%, 95% CI [7.4%, 8.7%]) and pulmonary rehabilitation (4.0%, 95% CI [3.6%, 4.5%]) among all patients. Quality indicator results varied across FP practices, particularly for provision of smoking cessation support to current smokers (median 67%, inter-quartile range [IQR] 44%), performing spirometry (median 53%, IQR 33%), administering pneumococcal (median 68%, IQR 29%) and influenza vaccines (median 61%, IQR 24%).

Conclusion: Primary care EMRs can be used to measure COPD quality indicators which are indicated for the majority of patients with COPD. Assessing appropriate COPD care based on level of COPD symptoms and severity would enhance COPD care assessment. Overall, the results suggest there is high variation across FP practices and there are opportunities for improved patient care in several areas of COPD management.

4.2 Introduction

Chronic obstructive pulmonary disease (COPD) is an incurable and progressive chronic condition and a leading cause of hospitalization and mortality worldwide.[151] There is substantial evidence that management of COPD is not in accordance with evidence-based guidelines[29,30,152–157], resulting in missed opportunities to reduce morbidity, mortality, hospitalization and health care costs. As the majority of patients with COPD are initially diagnosed and managed in primary health care settings, family physicians (FPs) play an important role in improving the quality of care and management of COPD in patients.

There is limited information on the quality of COPD care in primary care settings in Canada. The increased uptake of electronic medical records (EMRs) in primary care[158] provides a source of systematically collected longitudinal data that can be leveraged to attain information on the quality of care received by patients in real-world practice[102,159–163]. The objective of our study was to assess whether or not the quality of COPD management in primary care could be measured by comparing EMR data from FPs' practices in Ontario against a set of evidence-based COPD quality indicators. In addition to providing a reference against future changes in the management of COPD, measuring the current quality of COPD management in primary care practices establishes a baseline that can be used to evaluate the impact of targeted interventions, to identify populations at high risk, and to detect gaps in care that warrant further attention.

4.3 Methods

4.3.1 Study design

A cross-sectional study was conducted to measure the quality of care received by patients with COPD relative to a set of previously published evidence-based quality indicators[164]. Structured and semi-structured fields in primary care EMR data of Ontario patients were reviewed to identify the presence of indicated care at the population-level and at the physician-level. At the population-level, quality indicators were evaluated by the unadjusted proportion of eligible patients meeting the quality indicator criteria. At the physician-level, patients were linked to their FP and proportions of patients meeting the quality indicator criteria were aggregated by each FP's practice to assess the statistical dispersion in care provided across FP practices. This study

was approved by the institutional review board at Sunnybrook Health Sciences Centre in Toronto, Canada.

4.3.2 Setting and data source

The Electronic Medical Record Administrative data Linked Database (EMRALD®) held at the Institute for Clinical Evaluative Sciences (ICES), in Ontario, Canada[96,98] was used to measure COPD quality indicators. Ontario has a publicly-funded health care system and individuals may enroll and be 'rostered' to a FP's practice for comprehensive and continuous care. Our study was based on practice data contributed by FPs in Ontario who use Practice Solutions (PS) Suite EMR (TELUS Health, Montreal, QC), the most widely used primary care EMR software among Ontario FPs[165].

On average, EMRALD® physicians are representative of the typical Ontario physician, except they are slightly younger, more likely to be female, and more rural-represented than the typical Ontario physician.[96] EMRALD® provides a good representation of the general Ontario population in terms of age, sex, and measures of comorbidity.[96] EMRALD® includes all longitudinal patient chart data entered in the EMR dating back to the time the FP started using PS Suite EMR (from as far back as 1986), up to the time of data collection from the FP's practice. At the time of this study, the average physician in EMRALD® had used PS Suite EMR for 6 years.

4.3.3 Study population

The study cohort was derived from EMRALD® data collected between November 2013 and October 2014. To be eligible, FPs must have used the PS Suite EMR for at least two years so as to optimize the completeness of data.[96,98] Patients required a valid birthdate in the database, a valid health insurance number, enrollment in a study FP's roster, and at least one visit to the FP in the two years preceding the date of data collection. They also had to be over 40 years of age as of the time of data collection and have COPD according to the case-definition.

The case-definition for COPD consisted of presence of any of the following: having COPD recorded in the patient's problem list; at least three billing claims recorded for COPD (emphysema, chronic bronchitis, or other COPD) in one year; a prescription for long-acting anticholinergics at any time in the chart; or a prescription for short-acting anticholinergic

bronchodilator in conjunction with any COPD claims in the history of the chart[161]. This algorithm was validated against manual chart abstraction in a prior study, and had a positive predictive value of 93.6%, a sensitivity of 76.9% and a specificity of 99.7%.[161]

4.3.4 Measurement of quality indicators

We based our study on a comprehensive set of evidence-based quality indicators previously developed by the Ontario COPD Population Health Network using a modified RAND Appropriateness Method consisting of a systematic review and Delphi expert panel.[164,166] The final set of 33 COPD quality indicators[164] was reviewed by the study team to assess their measurability within the EMRALD® database. We determined that 11 quality indicators (see Appendix C) consisted of clinical information that was recorded in structured or semi-structured EMR fields and was searchable without natural language processing. For each of these quality indicators, we defined the numerator, denominator, exclusion, and timeframe criteria using a list of terms searchable in the EMR. The searchable EMR fields included data primarily populated in the FP's clinic, patient medical history, prescribed medication, diagnostic or laboratory test results received by the clinic, and title and content of electronic consultation letters or referrals. Information from specialist or emergency care, such as laboratory test results, spirometry results, prescriptions, hospital discharge summaries that were not recorded and converted into text-searchable format in the EMR were not included. The definition of the numerator, denominator, exclusion criteria, look-back time frames, and limitations to measurement are outlined for each quality indicator in the appendices. Microsoft Structured Query Language (SQL 2012) was used to search EMRALD® for defined terms and identifying the patients meeting the quality indicator criteria.

We did not have validated measures of COPD severity, dyspnea and exacerbations using our EMR data at the time of study, thus quality indicators applicable to only certain severities of COPD or acute exacerbations and dyspnea were either excluded or adapted to apply to all patients with COPD (regardless of severity or symptoms) in order to assess the feasibility of measuring them and identify current healthcare or medication utilization rates among all patients with COPD. The 22 quality indicators that could not be measured (see Appendix D) included quality indicators requiring search of unstructured free-text sources or administrative data sources. The quality indicators that could not be measured included care related to individualized comprehensive management plans, COPD action plans, advanced care directives, palliative care,

and if care was *offered* (but not necessarily delivered) to the patient. Quality indicators requiring hospitalization records of patients were excluded as they are not well recorded in primary care EMR data.[96]

4.3.5 Analysis

We summarized demographic information, including prevalence of comorbidities (stroke[129], atrial fibrillation[128], chronic kidney disease[124], ischemic heart disease or coronary artery disease[127], hypertension[124], diabetes[125,126]) based on previously validated EMR algorithms. At the population-level, all measurable quality indicators were evaluated by assessing the unadjusted proportion and 95% confidence intervals of eligible patients who met the numerator and denominator criteria, with the date of EMR data collection set as the index date.

At the physician-level, proportions of patients meeting the quality indicator criteria were aggregated by each FP's practice for FPs who had at least six patients with COPD in their roster. Physician-level variation was described with five-number summaries (minimum, lower quartile, median, upper quartile, and maximum), inter-quartile ranges (IQRs), means, standard deviations, coefficients of quartile deviation, and Pearson's second coefficient of skewness.

4.4 Results

4.4.1 Study population

We identified 6995 patients meeting the case-definition for COPD among 123,596 patients over the age of 40 (prevalence of 5.7%) who were rostered to study FPs meeting the study criteria (Figure 4-1). Four FPs who met the study criteria did not have any patients meeting the COPD case-definition. On average, 28 patients with COPD were rostered per FP, with a median of 19 patients (IQR [9-38]) and a maximum of 155 patients with COPD enrolled in a single FP practice. Thirty-one FPs had less than six patients meeting the COPD case-definition and were excluded from the physician-level analysis. As seen in Table **4-1**, the average age of a patient with COPD was 70 years, and 32.7% of patients were under the age of 65. Compared to all rostered patients over the age of 40, patients with COPD were older, had higher rates of comorbidity and were less frequently women.

4.4.2 COPD quality indicators in EMRALD®

Of the eleven quality indicators we assessed in the EMR database, five quality indicators were applicable to all patients with COPD. The total number, proportions and 95% CIs of patients with COPD meeting each quality indicator criteria are presented in Table **4-2**. The highest performing indicator was that 85% (95% CI [84.3-85.9%]) of patients had their smoking status recorded. Six of the assessed quality indicator criteria were met in at least 60% of the eligible patients. Only 54.8% (95% CI [53.6-55.9%]) of patients had evidence of spirometry in their records. The use of long-acting bronchodilators and short-acting bronchodilators were found in approximate three-quarters of our study population. Utilization rates intended for moderate or severe COPD (use of combination inhaled corticosteroids and long-acting bronchodilator, opioids, long-term oxygen therapy, pulmonary rehabilitation) were observed in less than a third of all patients with COPD.

When the proportions of patients meeting quality indicator criteria were aggregated by each FP's roster, a high degree of variation amongst practices was observed (Table 4-3). Figure 4-2 depicts the statistical distribution of proportions of patients in FPs' rosters meeting COPD quality indicator criteria. We found large variation in rates of vaccination, smoking intervention and spirometry. The top quartile of FPs provided influenza and pneumococcal vaccinations to nearly all of their COPD patients. Conversely, in the practices of the FPs in the lower quartile, only 16 to 50% and 12 to 54% of patients received influenza and pneumococcal vaccines respectively. FPs had high rates of recording patients' smoking status overall, but rates of smoking intervention for current smokers with COPD were low and had the largest absolute variation (median: 66.7, IQR: 39.7%) out of the eleven quality indicators. On average, about half the patients had spirometry recorded in their EMRs. The variation found in rates of spirometry was very high amongst physicians (median: 53.8%, IQR: 32.5%), with the upper quartile having records of spirometry for three-quarters of their patients, compared to 6 to 40% in the lower quartile.

Among all patients with COPD, prescription rates of long-acting (median: 78.0%, IQR: 19.3%) and short-acting anticholinergic (median: 75.0%, IQR: 18.7%) bronchodilators were high for most FP practices with relatively low levels of variation. In contrast, the proportion of patients with COPD who used combination inhaled corticosteroid and long-acting bronchodilators (median: 28.1%, IQR: 21.3%) and opioids (median: 13.6%, IQR: 12.4%) were much lower, with

relatively high levels of variation between FP practices as indicated by the coefficient of quartile deviation.

4.5 Discussion

We conducted a cross-sectional study in a primary care population representative of the Ontario population using real-world EMR data to study care provided to patients with COPD. We measured five evidence-based quality indicators appropriate for all patients with COPD, and additionally assessed four rates of medication utilization and two rates of healthcare utilization relevant to COPD care practices. We found suboptimal levels of various aspects of care for patients with COPD, particularly low rates of spirometry, smoking cessation support, influenza vaccination, pneumococcal vaccination and very limited use of pulmonary rehabilitation. Additionally, we found large variation between FPs' rosters in our secondary analysis.

Prevalence and practice patterns for COPD populations in Canada have been widely studied[28,31,152,157,160,167,168], however this is the first study in Canada, to our knowledge, that evaluates the quality of COPD care in primary care based on EMR data. COPD studies in Canada have mainly been conducted through surveys, questionnaires, manual chart review, case reports and administrative databases, and few focused on primary care. Only recently, has EMR data been used to identify and describe EMR-derived cohorts of COPD patients.[160,161] Outside of Canada, US-based studies have utilized EMR data to evaluate COPD management in both primary and tertiary care settings, and also identified sub-optimal aspects of COPD care[159,163,169–171]. US-based studies have examined barriers to COPD guideline adherence in primary care settings.[30,172–177] Similarly, several European countries have studied quality of COPD management and quality improvement methods in primary care[155,162,178–186]. Despite differences in data sources and settings, there were many consistencies between our findings and the results of these other studies.

Consistent with other studies, our study also found spirometry to be underutilized for patients with COPD diagnoses[157,171,174,177,181,187–192]. This is despite spirometry being feasible in primary care clinics with minimal training[154,193,194] and being beneficial for treatment decisions[195] and long-term patient health outcomes[195]. Our study found large variations in COPD care and treatment across primary care practices in Ontario, with the upper quartile of FPs having a

spirometry record for nearly all of their rostered patients with COPD, and the lower quartile of FPs having them for less than half. It is possible that the low level of spirometry recording is due in part to disease duration, which was not accounted for in our study, and would require consideration of the time of when the COPD was first diagnosed or when COPD medications were first prescribed. Given the importance of spirometry to inform management, this result suggests an opportunity to improve diagnosis, provide appropriate treatment and improve health outcomes[195]. While this study did not investigate the cause of the variation observed, Salinas et al. identified several barriers to the use of spirometry, including inaccessibility, FPs' perceptions such as disagreeing with spirometry guidelines, having low confidence in spirometry data interpretation, believing that spirometry was unnecessary to confirm suspicion, and/or the inability to integrate spirometry onsite.[174] Our research may aid in identifying benchmarking targets for spirometry.

While pneumococcal vaccinations rates in COPD populations have been studied in the US and Europe,[163,196–199] the present study is the first to our knowledge to report pneumococcal vaccination rates in Canada among patients with COPD. The pneumococcal vaccination rate of 66% found in our study was similar to rates found in Spain[200] and one study in the US[196], and higher than the vaccination rates of 5% to 36% reported elsewhere in US[198] and in other European countries, including Ireland[201], Norway[202], Germany and France[199,203]. The differences may be due to the number of elderly people in the study population as age is associated with higher rates of vaccination[200,201,204], recall bias in the case of self-reported surveys[203], different levels of awareness of the vaccine and its effectiveness[200,201,204], or insurance coverage or affordability of the vaccine. A Canadian study on knowledge, attitudes, beliefs and behaviours about pneumococcal immunization suggested that recommendation from a healthcare provider is the strongest predictor of vaccination and increased education could help achieve gains in coverage[204]. A 2015 Cochrane review found that pneumococcal vaccines can reduce hospitalization rates from COPD exacerbation, and can provide protection from infection[205], particularly to those under the age of 65 for whom the vaccine has shown most efficacy[206]. Our study found the lower quartile of FPs vaccinate only 12 to 54% of their patients with COPD. Fortunately, previous quality improvement efforts to increase pneumococcal vaccination rates have had success[196,207,208] and could be of interest for future research and implementation. We also found the rate of annual influenza vaccination to be lower than prior physician-reported

rates.[157] but consistent with rates reported in other primary care settings.[168,191] Underestimation in our data is possible due to the availability of influenza vaccines in community pharmacies through the *Universal Influenza Immunization Program in Ontario*[209], since vaccinations given outside of their practice may not be documented by some FPs.

Although we did not assess severity or symptoms, we found that short-acting bronchodilators and long-acting bronchodilators were prescribed to most patients with COPD. Short-acting bronchodilators were prescribed at a similar rate to a physician self-report survey[157] but more frequently than rates of short-acting beta-agonists suggested in previous Canadian studies[31,168]. Rates of prescription of long-acting bronchodilators were comparable to three studies[157,163,196], but much higher than the 6-43% reported in US studies with a different insurance system[170,176,177]. We found a slightly higher rate of use of long-acting bronchodilators in our study cohort compared to short-acting bronchodilators, which may reflect the nature of its inclusion in our COPD case-definition, which had a high positive predictive value, but may have not included patients with milder forms of COPD

The strengths of our study are that error of recall and biases of response are potentially reduced with EMR data compared to traditional surveys or questionnaires. The sampling population was representative of the general Ontario patient and FP populations. Compared to administrative data, EMR data contain medication prescription information of all patients regardless of age, including one-third of the study patients who are under the age of 65 and ineligible for our provincial public drug program. While hospital-based studies are more likely to have patients with higher severity of COPD due to exacerbation and admission, our study includes patients with COPD of all severities and provides an overall picture for the routine care in this population. Additionally, as the quality indicators were aggregated per FP practice, it is possible to assess the level of variation in practice among FPs to understand the quality of care from a system-level. While the present study was cross-sectional, the data is longitudinal and thus the findings can be used to study benchmarking and patterns in standard of care over time.

We had a number of limitations in our study. First, our study population was limited to our case-definition of COPD and would have missed patients with undiagnosed COPD. Second, we did not have a validated measure of COPD severity or exacerbation. Because PFT results are not fully standardized with regards to how their parameters and interpretations are recorded in the

EMR, it remains a challenge to validate COPD severity with EMR data alone. Quality indicators originally intended for a subset of patients with COPD (for certain severities or symptoms) were still included in our analysis to understand the medication and healthcare utilization rates; however, it reflected in our results as lower rates of combination inhaler use (corticosteroid and long-acting bronchodilator), opioid use, oxygen therapy and pulmonary rehabilitation, all of which would be appropriate quality indicators for those with more advanced stages of COPD. These results must be interpreted in this context and not as poor quality of care in our population. Despite this limitation, we felt that these utilization rates were still important to determine to establish the feasibility of measuring and reporting them as they are not widely reported at a population level. Future studies should examine more severe COPD population for in which higher levels of these QI should be found. It will be valuable to determine severity, disease duration, dyspnea and exacerbations within EMR data in order to evaluate the appropriateness of pharmacotherapy, access to pulmonary rehabilitation, oxygen therapy and potential patterns of overtreatment[210].

A third limitation is that it is possible that some patients received the care indicated in the quality indicator, but had insufficient electronic documentation in their EMR, thus lowering our result. For instance we found high rates documentation on patients' smoking history, but low rates of smoking cessation intervention among current smokers (64.3%, 95%CI [62.3, 66.4%]) relative to two survey-based studies reporting rates of 91%[175] and 95%[157]. It is possible that the patients' smoking histories was not updated, or that over-the-counter (OTC) smoking-cessation medications were advised for the patients but not documented in the EMR. Only the care recorded as being provided at the primary care clinic or retroactively added in the EMR charts could be included in this analysis. Any care provided outside of the FP's clinic, medications prescribed by specialists, OTC medication, hospitalization records that were not later documented in the primary care EMR were excluded. This highlights the value of EMR interoperability and communication of information between primary, tertiary and community health facilities. Additionally, it is possible that the necessary information for the remaining unmeasured quality indicators are detailed in the free-text EMR fields but could not be analyzed by the methods used in this study. Standardized ways of recording processes of care (such as electronic decision support or procedure codes) could improve measurability.

The fifth limitation is that variation in the adherence rates are likely due to in part to heterogenous patient populations in the different practices and variation in data recording. The physician-level variation was not adjusted for patient characteristics or size of each clinic and may influence practice patterns. For example, some physicians may be responsible for a larger number of patients with complex needs compared to other physicians, and some physicians may only have a small number of patients with COPD. Some of these potential effects were reduced by including only physicians with at least six patients with COPD in their practice. The variation may also reflect differences in documentation practice as some FPs may irregularly update the structured fields in the EMR. Future research with EMR should assess and adjust for known co-morbidities in patients with COPD who often have multiple chronic conditions.

A sixth limitation is that the indicators we measured were not comprehensive as we measured only the COPD quality indicators that were feasible to measure in our primary care EMR database. Although we report on important aspects of COPD care, we could not include information on all original 33 QIs, such as individualized plans, hospitalization, and advance care directives (see Appendix D).

Despite the highlighted limitations, our results are valuable to clinicians and researchers who are interested in COPD patient care. Future research should investigate how to identify patients with varying severities of COPD using EMR data, the cause of variation observed in patient care, and how to address some of the large gaps identified in COPD management in primary care practices. Clinical decision support tools and quality improvement programs can also be studied in this setting to evaluate the possibility of improving rates of smoking cessation counselling[211–213], vaccination[163,184,207], pulmonary rehabilitation[184].

4.6 Conclusion

The results from this study provide insight on practice patterns and highlight that several areas of COPD management require further consideration. There is great variation in how COPD is currently managed among FPs in Ontario. Future studies can explore the patient, physician or clinic factors that influence quality of COPD care. As COPD has a high cost to both quality of life and the health care system, FPs are in an important position to identify COPD and implement

preventive measures early to improve long-term outcomes; this study can provide a baseline against which to measure such initiatives.

4.7 Tables and figures

Table 4-1 Characteristics of study population with chronic obstructive pulmonary disease and all patients cared for by 251 physicians in EMRALD® practicing in 39 clinics in Ontario, Canada (2014)

	All patients (age ≥ 40 years) rostered to study family physicians*		Patients with chronic obstructive pulmonary disease	
Number of family physicians (n)	251		247	
Number of patients (n, %)	123 596	100	6995	5.7
Female (n, %)	70474	57.0	3588	51.3
Average age (years, SD)	60.1	12.9	70.4	11.9
Patients ≥ 65 years of age (n, %)	41734	33.8	4701	67.2
Patient average duration of EMR record (years, SD)	6.6	3.4	6.9	3.3
Comorbidities (n, %)				
Stroke	4262	3.4	641	9.2
Atrial fibrillation	5116	4.1	873	12.5
Chronic kidney disease	9313	7.5	1390	19.9
Ischemic heart disease	9065	7.3	1472	21.0
Hypertension	37524	30.4	3527	50.4
Diabetes mellitus	17349	14.0	1746	25.0

**including patients with chronic obstructive pulmonary disease*
EMR – electronic medical record; SD - standard deviation

Table 4-2 Proportions of patients with chronic obstructive pulmonary disease meeting various COPD quality indicator criteria in Ontario, Canada (2014)

Original Quality Indicator Description	**Adapted quality indicator measured in the primary care electronic medical record**	**Numerator (*n*)**	**Denominator (*n*)**	**Proportion of patients (%)**	**95% confidence interval *(%)***
Influenza vaccination received: Percentage of people with COPD who received an influenza immunization in the preceding flu season	[1] Percent of patients with COPD who received the influenza vaccine in the past 18 months	4233	6995	60.5	(59.4, 61.7)
Pneumococcal vaccination received: Percentage of people with COPD who received pneumococcal vaccination as per latest guidelines.	[2] Percent of patients with COPD who received a dose of pneumococcal vaccine at any time in the history of the chart (excluding those with an allergy to pneumococcal vaccines)	4621	6995	66.1	(65.0, 67.2)
Smoking assessment among non-smokers: Percentage of people with COPD who are non-smokers, including former smokers, who were asked about smoking status and secondhand smoke exposure in the last year	[3] Percent of percent of patients with COPD whose smoking status is recorded in the patients risk factors at any time in the history of the chart	5952	6995	85.1	(84.3, 85.9)
	Non-smoker	*607*	*6995*	*8.7*	*(8.0, 9.3)*
	Previous-smoker	*3222*	*6995*	*46.1*	*(44.9, 47.2)*
	Current smoker	*2123*	*6995*	*30.4*	*(29.3, 31.4)*
	Missing	*1043*	*6995*	*14.9*	*(14.1, 15.7)*
Smoking cessation intervention received: Percentage of people with COPD who are current smokers who received a smoking cessation intervention (e.g. counselling, pharmacotherapy) in the last year	[4] Percent of patients with COPD and recorded as current smoker who has smoking cessation drugs (see Appendix E) in their medication chart OR has smoking cessation/counselling claims (E079, K039, Q042A or bills labelled 'smoking cessation' or 'smoking consulting') at any time in the history of their chart	1366	2123†	64.3	(62.3, 66.4)
Spirometry to confirm diagnosis: Percentage of people with COPD who had their diagnosis confirmed by post bronchodilator spirometry	[5] Percent of patients with COPD who had pulmonary function tests recorded in their laboratory results at any time in the history of their chart	3831	6995	54.8	(53.6, 55.9)

Original Quality Indicator Description	Adapted quality indicator measured in the primary care electronic medical record	Numerator (*n*)	Denominator (*n*)	Proportion of patients (%)	95% confidence interval *(%)*
The following quality indicators were assessed for all patients with COPD regardless of symptoms or severity to look at utilization rates among all patients					
Long-acting bronchodilators for chronic disease management: Percentage of people with moderate to very severe COPD who were prescribed a long-acting beta agonist or long-acting muscarinic antagonist/long-acting anticholinergic bronchodilator, alone or in combination	[6] Percent of patients with COPD of any severity with long-acting bronchodilators in medication list (long-acting beta-agonist or long-acting anticholinergic) at any time in the history of the chart	5381	6995	76.9	(75.9, 77.9)
	Long-acting beta-agonist	*3884*	*6995*	56.1	(54.4, 56.7)
	Long-acting anticholinergic	*4622*	*6995*	66.1	(65.0, 67.2)
Short-acting anticholinergic bronchodilators for chronic disease management: Percentage of people with symptomatic COPD who were prescribed a short-acting beta-agonist or short-acting anticholinergic bronchodilator	[7] Percent of patients with COPD of any severity with short-acting anticholinergic bronchodilators in medication list (short-acting beta-agonist or short-acting anticholinergic) at any time in the history of the chart	5135	6995	73.4	(72.4, 74.4)
	Short-acting beta-agonist	*5009*	*6995*	71.6	(70.6, 72.7)
	Short-acting anticholinergic	*1114*	*6995*	15.9	(15.1, 16.8)
Combination Inhaled corticosteroids and long-acting bronchodilators for chronic disease management: Percentage of people with moderate to very severe COPD who had two or more exacerbations in the previous year who were prescribed inhaled corticosteroids with long-acting bronchodilators	[8] Percent of patients with COPD of any severity with combination inhaled corticosteroids and long-acting bronchodilators in the medication list (combination inhaler; or long-acting bronchodilators and a corticosteroid) at any time in the history of the chart	2164	6995	30.9	(29.9, 32.0)
Opioids: Percentage of people with very severe COPD and intractable dyspnea who were prescribed an opioid	[9] Percent of patients with COPD of **any severity** who have opioids prescribed at any time in the history of the chart‡	1091	6995‡	15.6	(14.7, 16.4)
Long term oxygen therapy (LTOT) assessment: Percentage of people with severe COPD and/or an oxygen saturation less than or equal to 88% when stable who are assessed for LTOT	[10] Percent of patients with COPD of **any severity** with oxygen therapy in the cumulative patient profile or treatments at any time in the history of the chart‡	564	6995‡	8.1	(7.4, 8.7)

Original Quality Indicator Description	**Adapted quality indicator measured in the primary care electronic medical record**	**Numerator (*n*)**	**Denominator (*n*)**	**Proportion of patients (%)**	**95% confidence interval *(%)***
Pulmonary rehabilitation referral: Percentage of eligible people with moderate to severe COPD who have ever been referred to a multidisciplinary pulmonary rehabilitation program meeting current standardized guidelines (This should include, as per latest guidelines and evidence, supervised individually tailored exercise training, structured education program, psychological support, multidisciplinary health care professional team, written exercise maintenance plan, and outcomes assessment)	[11] Percent of patients with COPD of **any severity** with pulmonary rehabilitation in consultation letters or in the patient cumulative patient profile at any time in the history of the chart‡	282	6995‡	4.0	(3.6, 4.5)

† Inclusion criteria: patients with COPD with a recorded current smoking history. The remaining quality indicators included all patients who met the COPD case-definition.

‡ No validated measure of COPD severity was available, thus the denominator included all patients meeting the case-definition for COPD

Table 4-3 Physician-level aggregate proportions of patients with COPD meeting quality indicator criteria per family physician practice for family physicians with at least 6 patients with COPD in their roster*

Original Quality Indicator Description	Adapted quality indicator measured in the primary care electronic medical record	Median (%)	Q_1 - 25th percentile (%)	Q_3 -75th percentile (%)	IQR Q_3 - Q_1 (%)	Min (%)	Max (%)	Pearson's second coefficient	Coefficient of quartile deviation	Mean (%)	SD (%)
Influenza vaccination received: Percentage of people with COPD who received an influenza immunization in the preceding flu season	[1] Percent of patients with COPD who received the influenza vaccine in the past 18 months (excluding those with an allergy to influenza vaccines)	61.3	50.0	72.8	22.8	15.8	100.0	-0.10	18.6	60.8	17.8
Pneumococcal vaccination received: Percentage of people with COPD who received pneumococcal vaccination as per latest guidelines.	[2] Percent of patients with COPD who received a dose of pneumococcal vaccine at any time in the history of the chart (excluding those with an allergy to pneumococcal vaccines)	69.1	54.1	81.9	27.8	12.4	100.0	-0.24	20.4	67.7	18.1
Smoking assessment among non-smokers: Percentage of people with COPD who are non-smokers, including former smokers, who were asked about smoking status and secondhand smoke exposure in the last year	[3] Percent of percent of patients with COPD whose smoking status is recorded in the patient risk factors at any time in the history of the chart	94.3	85.7	100.0	14.3	64.3	100.0	-1.07	7.7	86.9	20.9

Original Quality Indicator Description	Adapted quality indicator measured in the primary care electronic medical record	Median (%)	Q_1 - 25th percentile (%)	Q_3 -75th percentile (%)	IQR Q_3 - Q_1 (%)	Min (%)	Max (%)	Pearson's second coefficient	Coefficient of quartile deviation	Mean (%)	SD (%)
Smoking cessation intervention received: Percentage of people with COPD who are current smokers who received a smoking cessation intervention (e.g. counselling, pharmacotherapy) in the last year	[4] Percent of patients with COPD and recorded as current smoker who has smoking cessation drugs (see Appendix E) in their medication chart OR has smoking cessation/counselling claims (E079, K039, Q042A or bills labelled 'smoking cessation' or 'smoking consulting') at any time in the history of their chart†	66.7	44.1	83.8	39.7	0.0	100.0	-0.45	31.0	62.5	28.4
Spirometry to confirm diagnosis: Percentage of people with COPD who had their diagnosis confirmed by post bronchodilator spirometry	[5] Percent of patients with COPD who had pulmonary function tests recorded in their laboratory results at any time in the history of their chart	53.8	40.4	72.9	32.5	6.3	100.0	0.26	28.7	55.7	21.8
The following quality indicators were assessed for all patients with COPD regardless of symptoms or severity to look at utilization rates among all patients											

Original Quality Indicator Description	Adapted quality indicator measured in the primary care electronic medical record	Median (%)	Q_1 - 25th percentile (%)	Q_3 -75th percentile (%)	IQR Q_3 - Q_1 (%)	Min (%)	Max (%)	Pearson's second coefficient	Coefficient of quartile deviation	Mean (%)	SD (%)
Long-acting bronchodilators for chronic disease management: Percentage of people with moderate to very severe COPD who were prescribed a long-acting beta agonist or long-acting muscarinic antagonist/long-acting anticholinergic bronchodilator, alone or in combination	[6] Percent of patients with COPD of **any severity** with long-acting bronchodilators in medication list (long-acting beta-agonist or long-acting anticholinergic) at any time in the history of the chart	78.0	66.7	86.0	19.3	37.7	100.0	-0.40	12.7	76.1	14.0
Short-acting anticholinergic bronchodilators for chronic disease management: Percentage of people with symptomatic COPD who were prescribed a short-acting beta-agonist or short-acting anticholinergic bronchodilator	[7] Percent of patients with COPD of **any severity** with short-acting anticholinergic bronchodilators in medication list (short-acting beta-agonist or short-acting anticholinergic) at any time in the history of the chart	75.0	66.7	85.3	18.7	38.7	100.0	-0.29	12.3	73.3	17.1
Combination Inhaled corticosteroids and long-acting bronchodilators for chronic disease management: Percentage of people with moderate to very	[8] Percent of patients with COPD of **any severity** with combination inhaled corticosteroids and long-acting bronchodilators in the medication list	28.1	18.8	40.0	21.3	0.0	71.9	0.31	36.2	29.7	15.3

Original Quality Indicator Description	Adapted quality indicator measured in the primary care electronic medical record	Median (%)	Q_1 - 25th percentile (%)	Q_3 -75th percentile (%)	IQR Q_3 - Q_1 (%)	Min (%)	Max (%)	Pearson's second coefficient	Coefficient of quartile deviation	Mean (%)	SD (%)
severe COPD who had two or more exacerbations in the previous year who were prescribed inhaled corticosteroids with long-acting bronchodilators	(combination inhaler; or long-acting bronchodilators and a corticosteroid) at any time in the history of the chart										
Opioids: Percentage of people with very severe COPD and intractable dyspnea who were prescribed an opioid	[9] Percent of patients with COPD of **any severity** who have opioids prescribed at any time in the history of the chart‡	13.6	7.6	20.0	12.4	0.0	38.7	0.14	45.2	14.0	9.2
Long term oxygen therapy (LTOT) assessment: Percentage of people with severe COPD and/or an oxygen saturation less than or equal to 88% when stable who are assessed for LTOT	[10] Percent of patients with COPD of **any severity** with oxygen therapy in the cumulative patient profile or treatments at any time in the history of the chart‡	6.8	1.8	12.0	10.1	0.0	27.2	0.39	73.7	7.7	6.5

Original Quality Indicator Description	Adapted quality indicator measured in the primary care electronic medical record	Median (%)	Q_1 - 25th percentile (%)	Q_3 -75th percentile (%)	IQR Q_3 - Q_1 (%)	Min (%)	Max (%)	Pearson's second coefficient	Coefficient of quartile deviation	Mean (%)	SD (%)
Pulmonary rehabilitation referral: Percentage of eligible people with moderate to severe COPD who have ever been referred to a multidisciplinary pulmonary rehabilitation program meeting current standardized guidelines (This should include, as per latest guidelines and evidence, supervised individually tailored exercise training, structured education program, psychological support, multidisciplinary health care professional team, written exercise maintenance plan, and outcomes assessment)	[11] Percent of patients with COPD of **any severity** with pulmonary rehabilitation in consultation letters or in the patient cumulative patient profile at any time in the history of the chart‡	1.5	0.0	6.7	6.7	0.0	16.7	1.29	100.0	4.6	7.4

Q_1 – first quartile; Q_3 – third quartile; Min – minimum; Max; maximum ;IQR – interquartile range; SD – standard deviation (σ); Pearson's second coefficient $\left(\frac{3(mean-median)}{SD}\right)$ *; Coefficient of quartile deviation – a relative measure of dispersion based on the quartiles, calculated as* $\left(\frac{Q_3-Q_1}{Q_3+Q_1}\right)$

† Inclusion criteria: patients with COPD with a recorded current smoking history. The remaining quality indicators included all patients who met the COPD case-definition.

‡ The denominator included all patients meeting the case-definition for COPD as there was no validated measure of COPD severity

* This analysis includes summaries of patients who are rostered to family physicians that have at least 6 patients meeting the case definition of COPD in their practice (216 physicians, 6876 patients).

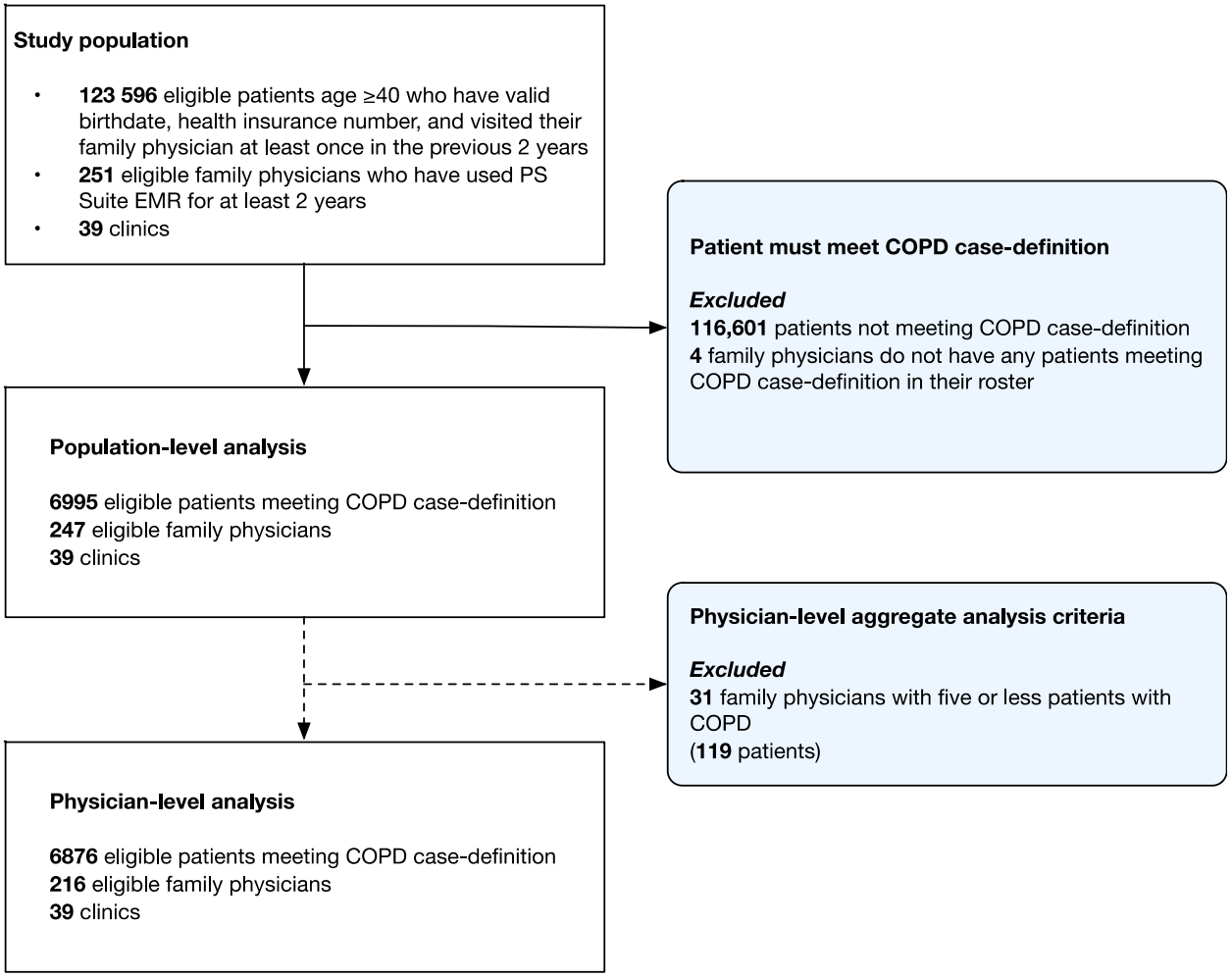
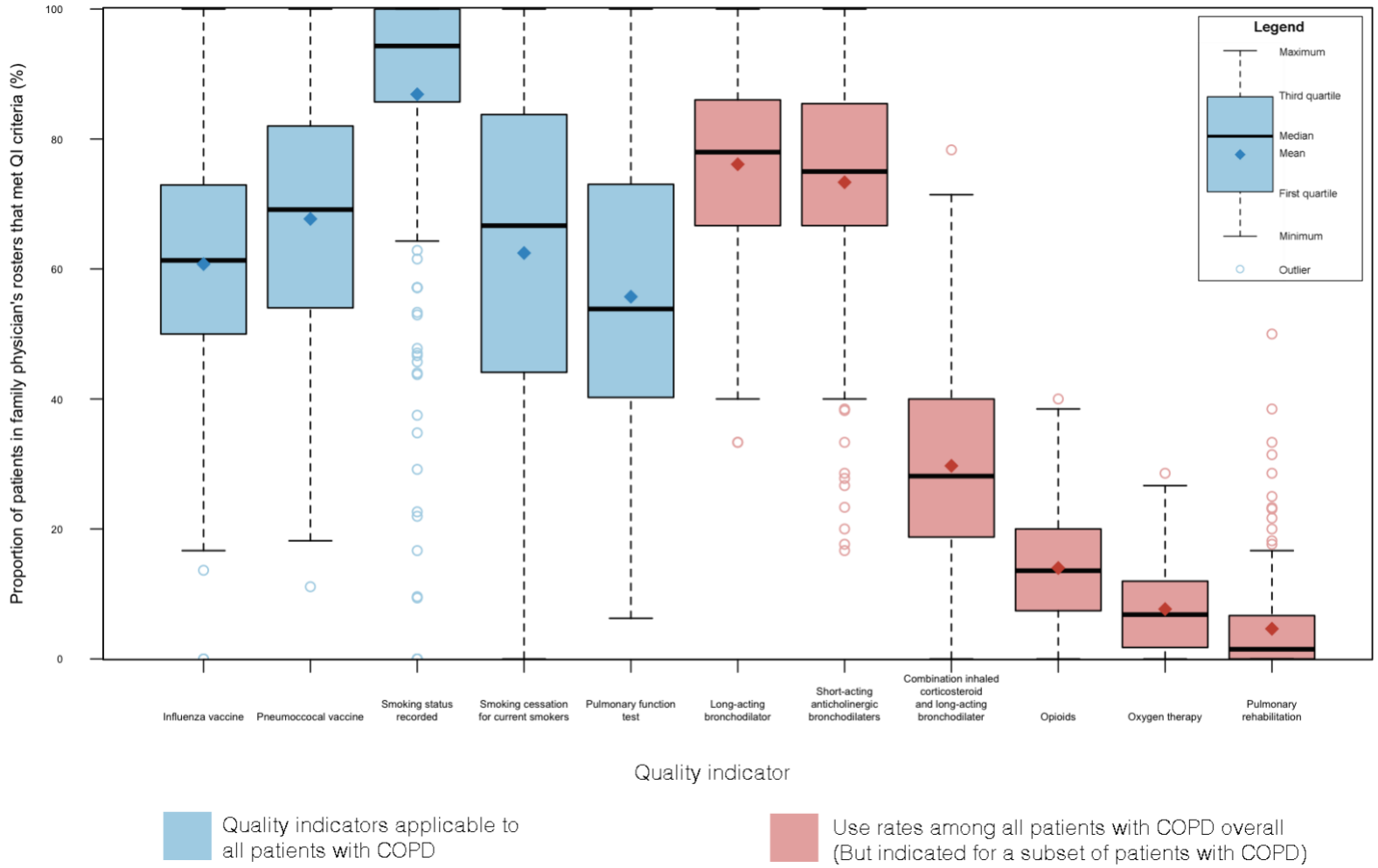


Figure 4-1 Study flow diagram



.

Figure 4-2 Boxplot depicting the distribution of proportions of patients across 216 family physicians' rosters who meet COPD quality indicator criteria (including mean, median, quartiles, 1.5 IQR minimum and maximum, and outliers) based on primary care electronic medical record data

Chapter 5

Analysis of individual and physician level factors associated with adherence to Canadian Cardiovascular Harmonized National Guidelines Endeavour (C-CHANGE) recommendations in primary care settings in Ontario: a retrospective population study using multilevel logistic regression analyses

The purpose of this chapter is to answer the question, "can EMR data be used to identify provider or patient characteristics that are associated with the provision or receipt of guideline adherent care in chronic disease management?" Answering this question would help identify patterns of chronic disease management in primary care practice and where quality improvement may be most needed. The objectives of this chapter are to:

1. Determine if EMR data in conjunction with administrative data can be used to determine what factors influence quality of primary healthcare at a population level;

2. Use multilevel modelling using EMR and administrative data to determine any provider-specific of patient-specific characteristics that are correlated with provision or receipt of cardiovascular care as recommended by the Canadian Cardiovascular Harmonized Guidelines Endeavour (C-CHANGE); and

3. Determine if there is variation in levels of adherence to C-CHANGE guidelines in primary care at the provider level or clinic level.

5.1 Abstract

Introduction: We previously found that there was large variation amongst family physicians in adherence to the Canadian Cardiovascular Harmonization of National Guidelines Endeavour (C-CHANGE). The purpose of this study was to assess the role of patient- or physician-level factors within indicator variation and to determine if there were characteristics of patients or physicians that contributed to variability in guideline adherence for the screening for, diagnosis and management of vascular disease and vascular disease risk factors.

Methods: We conducted a retrospective cross-sectional study using multilevel multivariable logistic regression analyses with the Electronic Medical Record Administrative data Linked Database (EMRALD®) housed at ICES in Ontario. Five quality indicators (QIs) based in five domains of the C-CHANGE published guidelines were modelled. We assessed the effects of clustering and between-group variation to determine odds ratios (and 95% confidence intervals) of receiving C-CHANGE recommended care by different patient-level characteristics (sociodemographic information, comorbidities) and physician-level characteristics (demographic and practice information). Proportion of variability attributable to both levels was determined.

Results: Our study population consisted of 324 Ontario family physicians practicing in 41 clinics who provided care to 227,999 adult patients. We found significant variation in QIs, with 15% to 39% of the total level of variation attributable to non-patient factors (physician-level and clinic-level factors). The largest variation was found in performing 2-hour plasma glucose testing in prediabetic patients. Patient-level factors most frequently associated with recommendation adherence included sex, age, and multi-comorbidities. Women were more likely than men to have their BMI measured, and have their blood pressure under control, and less likely than men to receive antiplatelets and liver enzyme testing.

Conclusion: The majority of variation in adherence to C-CHANGE recommendations were attributable to patient factors, but a substantial proportion of unexplained variation remained due to differences between physicians and clinics even after adjustment for clinical and demographic attributes at all levels. High variation found may signal suboptimal processes and structures at the system-level and warrant further investigation in order to improve the quality of primary care management of cardiovascular disease in Ontario.

5.2 Introduction

Cardiovascular disease (CVD) and its risk factors remain highly prevalent in Canada[17], including substantial levels of obesity, diabetes, hypertension, dyslipidemia and blood glucose.[214] Family physicians (FPs) have an important role in providing high quality care to help prevent, manage and improve CVD. To this end, the Canadian Cardiovascular Harmonized National Guidelines Endeavour (C-CHANGE) has amalgamated nine of Canada's cardiovascular-focused clinical practice guidelines to produce a harmonized set of key recommendations for primary care practitioners. In a previous study, we used primary care electronic medical records to show how well 23 cardiovascular care recommendations from the 2014 C-CHANGE guidelines[215] were being followed.[216] Despite the availability of guidelines based on best available evidence,[112,113,215] our results showed variable quality in several aspects of cardiovascular care in primary care settings in Ontario.

Adherence to quality indicators derived from previous iterations of C-CHANGE guidelines has been associated with fewer cardiovascular events.[217,218] To further study gaps in CVD care and identify characteristics of populations that may benefit from future guideline implementation efforts, we sought to assess patterns of clinical practice in the primary care setting. In this study, we looked to determine if there were patient or physician characteristics that were associated with patients receiving guideline-adherent care.

5.3 Methods

5.3.1 Data sources and study population

We conducted a retrospective cross-sectional study of factors related to guideline adherence using the **E**lectronic **M**edical **R**ecord **A**dministrative data **L**inked **D**atabase (EMRALD®) held at the ICES in Ontario.[13,14] We based the analysis on a study cohort previously described and derived from the EMRALD® database and included data contributed by FPs who used Telus Practice Solutions Suite EMR for more than 18 months. We further excluded data of patients rostered to the FPs if the patients were under the age of 18, or did not have a valid postal code as we could not obtain their neighbourhood income quintile data. The data were de-identified and linked using unique encoded identifiers and analyzed at ICES. Ethics approval was obtained from the institutional review board at Sunnybrook Health Sciences Centre, Toronto.

5.3.2 Outcome variables – C-CHANGE quality indicators

We evaluated all of the previously measured C-CHANGE indicators[216] for adherence at the patient and physician level and selected one indicator in each of the five C-CHANGE guideline categories measured: body habitus, diagnostic strategy, risk factors, treatment target and pharmacological therapies. We selected which specific quality indicator in each category to evaluate further based on a criteria of low-level of adherence and high level of variance at the physician level. These indicators and are summarized in Table **5-1**.

5.3.3 Explanatory variables

The following patient and physician characteristics were examined to see their association with guideline-based care.

Patient attributes: Patient attributes included age group, sex, rurality of residence (rural vs non-rural), socioeconomic status (approximated by neighbourhood income quintiles), comorbidity level (based on resource utilization bands calculated from the Johns Hopkins Adjusted Clinical Group® Case Mix System[130]), BMI category, and medical history. Patients' medical history was based on previously validated algorithms (presence or absence of atrial fibrillation[128], chronic kidney disease[124], ischemic heart disease or CAD[127], diabetes[125,126], hypertension[124] and stroke[129], or congestive heart failure[219]).

Physician attributes: Physician covariates included number of years in practice (every 5 years beyond 10), sex, place of medical training (Canada versus international medical graduate), and the size of their patient roster (measured per 100 patients above a roster size of 500).

5.4 Analysis

Non-independent observations and clustering of the data were accounted for by creating a three-level nested model with patients (level-1) nested within FPs' rosters (level-2) who were nested in their clinics where they practiced (level-3). The three-level hierarchical cross-sectional analysis fitted univariate dichotomous outcomes for each of the five quality indicators (QIs) individually to explore the associations between the receipt of the C-CHANGE recommendations and explanatory variables. Four models were created for each of the five QIs.

Models were first fitted in an (i) naïve (empty) model without any covariates (intercept-only) to assess for group effects at each level and used as a reference for comparing the size of contextual variation in rates of receiving recommended care. The naïve model shows the probability of patients meeting the quality indicator criteria as a function of the physician or clinic the patient is rostered to (which is accounted for by physician-level and clinic-level random intercepts). Hierarchical models were developed by sequentially adding the level 1 or level 2 explanatory variables as fixed effects to the empty models. This included (ii) a model including only patient attributes; (iii) a model including only physician attributes; and (iv) the complete model with patient and physician attributes. We estimated the effect of patient-level characteristics in the outcomes with group-specific random effects and random intercepts at the physician-level. This accounted for the clustered nature of the data and allowed us to explore contextual effects on the receipt of recommended care. Bias-corrected Akaike's information criteria (AICC)[220] were used for comparing and identifying the model that best accounted for the data.

We measured group-level heterogeneity and the magnitude of the effect of clustering by calculating the variance partition coefficients (VPCs) and the median odds ratios (MORs). The VPC estimates the proportion of the total variability observed that can be explained by differences between patient, physician roster or clinic. The MOR indicates how much a patient's odds of being provided the recommended care would increase if the patient moved to a different physician's roster or clinic with higher odds of providing the care. A higher MOR (> 1) means there is more variation between different clusters (FP rosters or clinics). This analysis was repeated for the five dichotomous outcomes.

We analyzed coded data using SAS v9.2 (SAS Institute Inc, Cary, NC) and Microsoft Structured Query Language 2012 (Microsoft Corp, Redmond, WA). The hierarchical generalized linear mixed models with random effects were fitted with SAS PROC GLIMMIX with the Laplace method, logit link function and Cholesky parameterization. The magnitudes of effects were exponentiated and measured as odds ratios (ORs) with corresponding two-sided 95% confidence intervals. Associations were considered as significant when the p-value was below 0.05.

5.5 Results

5.5.1 Study population characteristics

Our study population included 227,999 patients rostered to 324 physicians practicing in 41 clinics. In-depth descriptions of the study population and study physicians and how the quality indicators were measured at the patient level were provided in a previous study.[216] The study population's age distribution, level of comorbidity according to resource utilization bands, and prevalence of chronic conditions for each of the five quality indicators are summarized in Table 5-2.

5.5.2 Variation in meeting criteria of quality indicators due to group effects

The measurements of components of variance and heterogeneity in the probability of patients meeting the five C-CHANGE quality indicators are summarized in Table **5-3**. This includes the proportion of total variability in quality indicators being met that were attributable to physician or clinic attributes, the median odds ratios at the physician and clinic level and model fit statistics for each of the four models corresponding to one of the five quality indicators.

Patient-level differences contributed the most to whether or not the quality indicator criteria were met in all of the indicators. However, the hierarchical logistical multi-level regression models showed that the probability of C-CHANGE adherent care was strongly influenced by both patient and physician characteristics in all instances. In addition, there were significant amounts of variability in the odds of patients receiving C-CHANGE adherent care between FP rosters and clinics, with 15% or more of the proportion of total variability being attributable to non-patient factors (physician or clinic level differences). The highest level of variability due to non-patient factors were found in whether or not patients received a 2-hour plasma glucose test after receiving haemoglobin A1c or fasting plasma glucose (FPG) test results that indicate pre-diabetes. The lowest level of variability in-between groups at both the physician and clinic levels was found in the outcome-based indicator of whether or not patients with diabetes achieved blood pressure targets of less than 130 over 80 mmHg.

Median odds ratios at the physician-level and clinic-level were visualized at the bottom of Figure 5-1 Fixed effects of patient and physician attributes on the odds ratios of having the patient's body mass index recorded (67.3%) and the variability attributing to odds at the patient, physician

and clinic levels (n = 227,999) to Figure **5-5** to depict the variability due to group-level heterogeneity relative to measured attributes. The MORs were substantial at both physician and clinic levels, ranging from 1.6 to 2.9, which suggest that there were unexplained heterogeneity at the physician and clinic-level, beyond the parameters included in our model, that influenced whether or not patients met the quality indicator criteria.

5.5.3 Fixed effects of explanatory variables

We found several statistically significant associations between receiving C-CHANGE recommended care and patient and physician attributes. The associations with the measured fixed effects and five quality indicators are reported by ORs, their 95% confidence intervals and p-values presented in Figures 1 to 5, with each figure depicting one of the five quality indicators. Compared to physician-level factors, patient-level characteristics were more frequently statistically significant in their association with meeting the quality indicator criteria.

After controlling for all other patient and physician-level factors, women had higher odds of having their body mass index recorded (OR 1.76 [1.72-1.80]) and having their blood pressure at target level if they were diabetic (OR: 1.09 [1.02-1.16]). However, they had lower odds of receiving anti-platelets if they had coronary artery disease (OR: 0.77 [0.70-0.85]). Presence of comorbidities was associated with meeting two of the quality indicator criteria (receiving a liver enzyme test when overweight and receiving antiplatelet therapy) as reflected by increase in odds ratios with each increase in the patients' resource utilization band. In particular, patients with diabetes were more likely to have their BMI recorded (OR 1.98 [1.90-2.06]) and receive a liver enzyme test if they were overweight (OR 4.47 [4.19-4.76]). Patients with stroke had higher odds of receiving antiplatelet therapy (OR 1.93 [1.68-2.22]) while patients with atrial fibrillation had half the odds (OR: 0.49 [0.43-0.56]) after adjusting for patient and physician factors.

Patients were more likely to have their BMI recorded with each increase in resource utilization band from 0 (lowest) to 3. With higher resource use (bands 4 and 5, the highest) the odds declined. This is reflective of our finding that patients were less likely to have their BMI recorded if they had a history of chronic kidney disease (OR: 0.82 [0.77-0.86]), congestive heart failure (OR: 0.60 [0.56-0.64]), or stroke (OR: 0.74 [0.69-0.79]).

Although nearly 64% of patients with congestive heart failure had a BMI measurement, we found that BMI was less likely to be recorded for patients who had CHF when controlling for all

other parameters. This result was surprising as monitoring weight is recommended for patients with CHF and FPs are incentivized to measure the weight of these patients in the CHF management billing incentive. To understand if weight was monitored and FPs merely did not measure the height of their CHF patients in order to calculate BMI, we verified the odds ratio of having a weight measurement recorded in the EMR as opposed to a calculated BMI measurement. A higher proportion of patients had a weight measurement in the EMR overall compared to BMI, and 84% of patients with CHF had their weight recorded. Despite this, when accounting for all other demographic and available clinical factors, patients with CHF were less likely to have their weight measured (as well as BMI) as well compared to patients without CHF (OR 0.72 [0.71-0.84]).

When considering physician-level attributes, family physicians who were international medical graduates were more likely to have their patients' blood pressure under the target if they were diabetic (OR: 1.22 [1.03-1.45]). Physicians who have been practicing for longer were less likely to order 2-h plasma glucose tests (OR: 0.88 [0.81-0.95]) as were physicians who had larger roster sizes (OR: 0.86 [0.78-0.96]). Family physicians with larger roster sizes were also associated with lower odds of having patients with coronary artery disease receive antiplatelet therapy (OR 0.95 [0.91-0.98]).

5.6 Discussion

Our retrospective cross-sectional study using patient-level primary care EMR data from 227,999 patients cared for by 324 physicians in Ontario showed widespread variation in the provision of cardiovascular screening, management and care for patients. Large practice variation across a jurisdiction can indicate that there are gaps in quality of care, or that there are gaps in knowledge of best evidence in the healthcare system.[88] Variations can further signal that inequities or disparities in quality exist, such that certain groups of the population are less likely than others to receive evidence-based care.[88] By creating a series of multilevel multivariable generalized linear models of quality indicators based on C-CHANGE recommendations, we were able to quantify the level of variation found between physicians and between clinics. Further, we found several patient and clinic-level factors associated with the degree of adherence to the recommended care, signalling certain populations may be at higher risk of falling through gaps in health care. We found that some of the results were consistent with findings from other studies. Patients with

diabetes or higher healthcare resource use were generally more likely to receive recommended care, which could be due to heightened perceived risk, and more frequent clinic visits.

We found that patients with CHF had lower odds of having their BMI recorded when adjusted for all other sociodemographic factors. This surprising result may, in part, be due to the prioritization of other medical problems during the patient-physician encounter, since patients with CHF are generally sicker. Patients with CHF may be visiting specialists in addition to their primary care physicians, and the specialists may be assuming the responsibility monitoring their weight. The prioritization of other issues during the clinical encounter with FPs may also explain the reduced odds of BMI measurement for patients with CKD and stroke. As obesity becomes an increasing concern in Canada, it will be important to ensure that BMI is monitored in order to better assess risk[221] and for FPs to encourage and guide patients to maintain a healthy weight, particularly for populations at higher risk. Each opportunity to measure BMI is an opportunity to assess risk and offer counselling or support to reduce patient risk. Patients usually see FPs more frequently than specialists, so it is important that FPs measure and monitor patients' weight regardless of if weight is being monitored by specialists.

The highest level of variance was found in performing two-hour oral glucose tolerance tests when patients received results that indicate prediabetes (FPG 6.1-6.9 mmol/L and/or haemoglobin A1c 6.0-6.4%). There were high levels of variation in practice at both the clinic and physician-level with nearly 40% of the variation being attributable to non-patient factors. Our model only identified the rurality of patient's residence, obesity, physician's years in practice and their roster size to be statistically significantly associated with having the oral glucose tolerance test performed. With a high median odds ratio of 2.47 at the clinic level and 2.86 at the physician level, the results imply that other unknown factors remain absent from our model. Potential factors influencing the infrequent use of the 2-hour oral glucose tolerance test include physician attitudes towards value of the test, perceived inconvenience of the test (such as reduced accessibility to the test if it is not offered at all laboratories, scheduling the test and duration of the test), perceived cost versus benefit of the performing the test over another, or lack of awareness of the recommendation.

Anti-platelets such as acetylsalicylic acid (ASA) are often purchased over-the counter and may evade recording in the primary care EMR or be recorded in the free text portions of the EMR less

amenable to automated analysis. This may partially explain the low rate of 48% of patients receiving antiplatelets when they have coronary artery disease in the study population. In our model, we found women had lower odds of receiving antiplatelets than men after controlling for all other factors. The difference may be in part due to perceived differences in risk versus benefit, including the effectiveness of anti-platelets for women versus men, and risk of adverse drug events or bleeding.[222–224] However, studies have shown that, despite sex differences, antiplatelet therapy remains beneficial in reducing stroke[222]. We found more than double the odds of antiplatelet use among patients with a history of a stroke (OR: 2.01 [1.75-2.32]) which is consistent with its use for secondary prevention[225].

5.6.1 Strengths and limitations

This study was conducted in multiple primary care settings with a large study population. This study shows that routinely collected patient-level data from EMRs in primary care can be used to monitor quality and assess its determinants in a systematic way. We found important differences in processes of care that warrant further attention.

The use of EMRs comes with limitations. Notably, there can be underreporting during the initial period of implementation and variability resulting from heterogeneity in coding. We attempted to account for this by including data from FPs who had used EMRs for at least 18 months (the average duration of time the FPs used the EMR was 6.1 years). However, these issues may contribute to the disparities found in our study. To further reduce capturing the heterogeneity of data recording practice, we considered only QIs that were measurable with variables in structured and semi-structured fields which were consistently used among FPs.

We were unable to study why patients did not receive recommended prescriptions or tests at the individual level beyond the characteristics which were modelled. For example, we were unable to determine whether patients declined recommended prescriptions and tests when they were offered, if they were experiencing side effects, or if they were not being offered in the first place. We were, however, able to account for scenarios in which medications were prescribed and later discontinued if they were marked as discontinued in the EMR. We also did not explore the possibility that FPs treated certain groups less aggressively than others (if the FP perceived these groups to be at lower risk).

Our simplified models showed statistically significant variation between groups at the physician and clinic levels and thus we compared models with physician-level factors for all QIs. We did not include any cross-level interactions in our model (interaction of factors across the patient-, physician- or clinic-level). However, the standard errors, confidence intervals and p-values of the regression coefficients we reported are likely conservative, particularly at the physician or clinic-levels due to the nature of hierarchical models.

5.7 Conclusion

Our retrospective population-based study found that patient characteristics accounted for the majority of variability found in aspects of cardiovascular care in primary care settings. However, our results indicate FP and clinic differences made a significant contribution to the variability in certain aspects of care, suggesting there may be system-level issues that can be addressed. Future studies should investigate if the differences found in the odds of receiving recommended care in certain groups of patients are warranted, so as to ensure accessibility and equitability primary care. Our findings can be considered in future efforts to ensure that all patients receive the recommended care to reduce CVD risk and improve adherence to beneficial treatments. Strategies that target quality improvement in this area should consider multilevel interventions that include individuals as well as clinics that influence healthcare service delivery.

5.8 Tables and figures

Table 5-1 Description of modelled C-CHANGE quality indicators

Quality indicator	Domain	Original C-CHANGE recommendation	Adapted quality indicator	Inclusion/exclusion criteria
1) Body mass index recorded	Body habitus	Height, weight and waist circumference should be measured and body mass index calculated for all adults. (Canadian Association of Bariatric Physicians and Surgeons, Obesity Canada)	Patient has their BMI recorded in the EMR: % of adults with a body mass index (BMI) recorded [Lookback: All time] Height, weight and waist circumference should be measured, and BMI calculated for all adults.	Include: All patients meeting study criteria
2) Liver enzyme tests in patients with high BMI	Diagnostic Strategies	Additional investigations, such as liver enzyme tests, and sleep studies (when appropriate), to screen for and exclude other common overweight/obesity-related health problems. (Canadian Association of Bariatric Physicians and Surgeons, Obesity Canada)	Patient with a BMI ≥ 25.0kg/m2 has had a liver enzyme test in the last 3 years: % of patients with a BMI ≥ 25.0, with a liver test [Lookback: 3 years] Additional investigations, such as liver enzyme tests, urinalysis and sleep studies (when appropriate), to screen for and exclude other common overweight/obesity-related health problems.	Include: Patients with a BMI measurement Exclude: Patients whose most recent BMI measurement is ≤25kg/m2
3) 2-hour plasma glucose test (2hPG)	Risk Factor Screening	Testing with 2hPG in a 75 g OGTT may be considered in individuals with FPG 6.1-6.9 mmol/L and/or A1C 6.0%-6.4% in order to identify individuals with lGT or diabetes. (Diabetes Canada)	Patient who has not been previously diagnosed with diabetes who has had a fasting plasma glucose of 6.1-6.9 mmol/L and/or HbA1c of 6.0%-6.4%, has received a 2h plasma glucose oral glucose tolerance test: % of patients ≥ 18 with FPG 6.1-6.9 and/or HbA1c 6.0%-6.4%, and a 2hPG test [Lookback: All time] Testing with 2hPG in a 75 g OGTT should be undertaken in individuals with FPG 6.1-6.9 mmol/L and/or A1c 6.0%-6.4% in order to identify individuals with IGT or diabetes.	Include: Patients with a fasting plasma glucose of 6.1-6.9 mmol/L and/or HbA1c of 6.0%-6.4% Exclude: Patients with diabetes
4) Blood pressure (BP) target	Treatment targets	Persons with diabetes mellitus should be treated to attain systolic BP of <130 mm Hg and diastolic BP of <80 mm Hg (these target BP levels are the same as BP treatment thresholds). (Diabetes Canada)	Patient with diabetes who has a most recent BP of less than < 130/80 in the last year: % of patients with diabetes with most recent BP < 130/80 [Lookback: 1 year] Persons with diabetes mellitus should be treated to attain systolic blood pressures of less than 130 mmHg and diastolic blood pressures of less than 80 mmHg. (These target blood pressure levels are the same as the blood pressure treatment thresholds.	Include: Patients with a blood pressure reading from within 1 year of date of data collection Exclude: Patients without diabetes
5) Anti-platelet medication	Pharmacologic and/or Procedural Therapy for CVD Risk Reduction Coronary	Antiplatelet therapy: all patients with ischemic stroke or transient ischemic attack should be prescribed antiplatelet therapy for secondary prevention of recurrent stroke unless there is an indication for anticoagulation. (Heart and stroke foundation)	Patient with coronary artery disease (CAD) who has a prescription for an anti-platelet agent in the last 18 months: % of patients with CAD and a prescription for anti-platelet agents [Lookback: 18 months] Patients with documented coronary artery disease, in the absence of specific contraindications or documented intolerance, should be treated with anti-platelet agents; for patients with a history of chronic stable angina, remote PCI, or CABG, ASA (75 mg PO to 162 mg) PO daily indefinitely	Exclude: Patients without coronary artery disease

Table 5-2 Characteristics of patients and physicians included in the analysis of factors associated with meeting five different C-CHANGE quality indicators

Quality indicator†	**1. BMI recorded**		**2. Liver enzyme test**		**3. 2hPG**		**4. BP < 130/80**		**5. Antiplatelet**	
Number of patients	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Total number of patients	227,999	100.0	98,687	100.0	23,297	100.0	18,309	100.0	10,327	100
Quality indicator met	153,387	67.3	63,463	48.2	2,218	9.2	6,985	38.2	4,934	47.7
Sex										
Female	129,420	56.8	53691	54.4	12,134	52.1	8,660	47.3	3,468	33.6
Male	98,579	43.2	44996	45.6	11,163	47.9	9,649	52.7	6,859	66.4
Age group, years										
18 to 34	56989	25.0	15277	15.5	542	2.3	468	2.6	11	0.1
35 to 49	63868	28.0	26917	27.3	3345	14.4	2191	12.0	414	4.0
50 to 64	61557	27.0	32559	33.0	9112	39.1	6603	36.1	2807	27.2
65 and over	45585	20.0	23934	24.3	10298	44.2	9047	49.4	7095	68.7
Residence location										
Rural	45,634	20.0	23068	23.4	5,651	24.3	4,749	25.9	2,806	27.2
Urban	182,365	80.0	75619	76.6	17,646	75.7	13,560	74.1	7,521	72.8
Income quintile										
1st (Lowest)	39,380	17.3	16660	16.9	4,174	17.9	4,064	22.2	2,064	20.0
2nd	40,680	17.8	18001	18.2	4,231	18.2	3,795	20.7	2,007	19.4
3rd	41,993	18.4	18765	19.0	4,357	18.7	3,379	18.5	1,838	17.8
4th	47,567	20.9	21158	21.4	4,873	20.9	3,498	19.1	2,004	19.4
5th (Highest)	58,379	25.6	24103	24.4	5,662	24.3	3,573	19.5	2,414	23.4
Past Medical history										
Atrial fibrillation	5,818	2.6	3184	3.2	1,526	6.6	1,422	7.8	1,469	14.2
Chronic kidney disease	9,382	4.1	5348	5.4	2,337	10.0	2,884	15.8	2,032	19.7
Congestive heart failure	5,954	2.6	3003	3.0	1,377	5.9	1,951	10.7	2,384	23.1
Coronary artery disease	10,327	4.5	6030	6.1	2,611	11.2	3,194	17.4	10,327	100.0
Diabetes	21,663	9.5	14967	15.2	na	na	18,309	100.0	3,603	34.9
Hypertension	46,507	20.4	28556	28.9	10,172	43.7	11,483	62.7	6,142	59.5
Stroke	5,093	2.2	2554	2.6	1,126	4.8	1,270	6.9	1,121	10.9
Body mass index										
Normal (≤25kg/m2)	na	na	na	na	3,520	15.1	2,007	11.0	1,387	13.4
Overweight (25-30kg/m2)	na	na	51948	52.6	6,596	28.3	4,629	25.3	2,880	27.9
Overweight (>30kg/m2)	na	na	46739	47.4	7,977	34.2	8,688	47.5	3,145	30.5
Missing value	na	na	na	na	5,204	22.3	2,985	16.3	2,915	28.2
Resource utilization band *										
0 (Lowest utilization)	12,610	5.5	3778	3.8	514	2.2	20	0.1	85	0.8
1	11,542	5.1	3888	3.9	424	1.8	32	0.2	31	0.3
2	39,912	17.5	15364	15.6	2,509	10.8	1,414	7.7	333	3.2
3	116,197	51.0	54063	54.8	13,116	56.3	10,239	55.9	4,417	42.8
4	34,590	15.2	15320	15.5	4,177	17.9	3,689	20.2	2,906	28.1
5 (Highest utilization)	13,148	5.8	6274	6.4	2,557	11.0	2,915	15.9	2,555	24.7
Number of physicians	**i**	**%**	**i**	**%**	**i**	**%**	**i**	**%**	**i**	**%**
Total Number of physicians	324		324		324		324		321	
Doctor's sex										
Female	182	56.2	182	56.2	182	56.2	182	56.2	179	56.8
Male	142	43.8	142	43.8	142	43.8	142	43.8	142	44.2
Medical training location										
Canada	294	90.7	294	90.7	294	90.7	294	90.7	291	90.7
International	30	9.3	30	9.3	30	9.3	30	9.3	30	9.3
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Years in practice	20.8	11.3	20.8	11.3	20.8	11.3	20.8	11.3	20.9	11.3
Doctor's roster size (all ages)	882.3	498.6	882.3	498.6	882.3	498.6	882.3	498.6	888.8	496.5
Number of clinics	**j = 41**		**j = 41**		**j = 41**		**j = 41**		**j = 41**	

†Please refer to Table 5-2 for the full description of the quality indicators.

* Resource utilization band (RUB) is the mean resource intensity weight using any diagnosis from a MD or NP encounter, physician claim, emergency department visit or hospitalization in the past year. Resource Utilization Bands (RUBs) are part of the Johns Hopkins Adjusted Clinical Group® (ACG®) Case Mix System. The RUBs are a simplified ranking system of each person's overall sickness level, taking into account all the diagnoses attributed to them during medical visits and hospitalizations in the preceding year. RUB 0-Non-user; 1-Healthy User; 2-Low Morbidity; 3-Moderate Morbidity; 4-High Morbidity; 5-Very High Morbidity.

na, not applicable

Table 5-3 Measures of components of variance and heterogeneity in the probability of patients meeting C-CHAGE quality indicator criteria

Quality indicator†	**1. Patient has their BMI recorded in the EMR**				**2. Patient with a BMI ≥ 25.0kg/m2 has had a liver enzyme test in the last 3 years**				**3. Patient who has had a fasting plasma glucose of 6.1-6.9 mmol/L and/or HbA1c of 6.0%-6.4%, has received a 2h plasma glucose oral glucose tolerance test**				**4. Patient with diabetes who has a most recent BP of less than < 130/80**				**5. Patient with coronary artery disease (CAD) who has a prescription for an anti-platelet agent in the last 18 months**			
Model*	***i***	***ii***	***iii***	***iv***	***i***	***ii***	***iii***	***iv***	***i***	***i***	***ii***	***iii***	***iv***	***ii***	***iii***	***iv***	***i***	***ii***	***iii***	***iv***
Proportion of total variability (%)																				
Clinic-level	0.155	0.16	0.16	0.163	0.067	0.087	0.065	0.085	0.274	0.065	0.068	0.066	0.07	0.276	0.278	0.166	0.106	0.104	0.097	0.077
Physician-level	0.155	0.158	0.152	0.156	0.147	0.162	0.146	0.162	0.19	0.082	0.084	0.079	0.08	0.188	0.183	0.224	0.117	0.118	0.115	0.119
Patient-level	0.69	0.683	0.688	0.681	0.785	0.751	0.789	0.752	0.536	0.853	0.848	0.856	0.85	0.536	0.539	0.609	0.777	0.778	0.788	0.804
Median Odds Ratio																				
Clinic-level	2.27	2.31	2.30	2.33	1.66	1.8	1.64	1.79	3.45	1.61	1.63	1.62	1.64	3.46	3.47	2.47	1.89	1.88	1.84	1.71
Physician-level	2.27	2.3	2.25	2.29	2.11	2.23	2.1	2.23	2.8	1.71	1.72	1.69	1.7	2.79	2.74	2.86	1.96	1.96	1.94	1.94
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Model fit																				
AICC	251854.7	240517.1	251854.9	240521.3	120365.4	101154.9	120362.3	101159.8	11156.6	239807.2	23396	239804.7	23392.1	11116.4	11147.3	11142.5	13656.3	13222.3	13650.3	13224.8
-2 Log Likelihood	251,848.7	240469.1	251840.9	240465.3	120359.4	101106.9	120348.3	101103.7	11,150.6	239801.2	23343.9	239700.7	23332	11064.3	11133.3	11082.4	13,650.3	13170.2	13636.3	13164.6
n	227 999				98 687				23 297				18 309				10 327			
Quality indicator met %	67.3				64.3				9.5				38.2				47.8			

†Please refer to Table 1 for the full description of the quality indicators.

*i: Naïve model; ii: Patient attributes; iii: Physician attributes; iv: Patient and physician attributes

AICC - Corrected Akaike information criterion

	Odds ratio (95%CI)	P-value
Patient attribute fixed parameters		
Female (reference male)	1.76 (1.72-1.80)	<.0001
Age (years) 18 to 34	Reference	
35 to 44	1.57 (1.53-1.61)	<.0001
45 to 64	2.26 (2.20-2.33)	<.0001
65 to 84	1.99 (1.92-2.06)	<.0001
Rural (reference urban)	1.06 (1.02-1.10)	0.0065
Income quintile: 1st	Reference	
2nd	1.09 (1.05-1.12)	<.0001
3rd	1.13 (1.10-1.17)	<.0001
4th	1.18 (1.14-1.22)	<.0001
5th (Highest quintile)	1.22 (1.18-1.26)	<.0001
Previous medical history: atrial fibrillation	1.04 (0.97-1.11)	0.3206
Chronic kidney disease	0.82 (0.77-0.86)	<.0001
Congestive heart failure	0.60 (0.56-0.64)	<.0001
Coronary artery disease	0.99 (0.94-1.05)	0.8125
Diabetes	1.98 (1.90-2.06)	<.0001
Hypertension	1.11 (1.08-1.14)	<.0001
Stroke	0.74 (0.69-0.79)	<.0001
Body mass index: Normal (≤25kg/m^2)	-	-
Overweight (25-30kg/m^2)	-	-
Obese (>30kg/m^2)	-	-
Missing	-	-
Resource utilization band: 0	0.47 (0.45-0.49)	<.0001
1	0.74 (0.71-0.77)	<.0001
2	0.83 (0.81-0.86)	<.0001
3	Reference	.
4	0.96 (0.93-0.98)	0.0026
5 (Highest utilization)	0.81 (0.77-0.85)	<.0001
Family physician attribute fixed parameters		
Doctor is female	1.09 (0.90-1.32)	0.3908
Years in practice (Per 5 years past 10)	1.00 (0.96-1.04)	0.9176
International medical graduate	1.19 (0.88-1.61)	0.2692
Roster size: per 200 patients above 800	0.97 (0.93-1.03)	0.3337
Median odds ratios		
Clinic-level median odds ratio	2.33	<.0001
Physician-level median odds ratio	2.29	<.0001

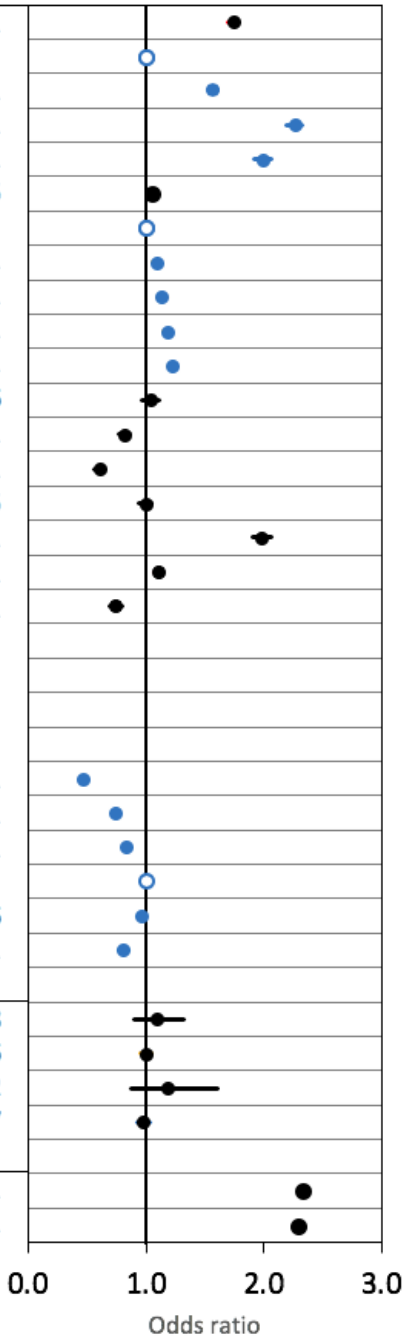


Figure 5-1 Fixed effects of patient and physician attributes on the odds ratios of having the patient's body mass index recorded (67.3%) and the variability attributing to odds at the patient, physician and clinic levels (n = 227,999)

	Odds ratio (95%CI)	P-value
Patient attribute fixed parameters		
Female (reference male)	0.95 (0.92-0.98)	0.004
Age (years) 18 to 34	Reference	
35 to 44	1.94 (1.86-2.04)	<.0001
45 to 64	3.06 (2.92-3.21)	<.0001
65 to 84	3.91 (3.69-4.15)	<.0001
Rural (reference urban)	0.95 (0.90-1.00)	0.0683
Income quintile: 1st	Reference	
2nd	0.94 (0.89-0.99)	0.0216
3rd	0.92 (0.87-0.97)	0.0016
4th	0.88 (0.84-0.93)	<.0001
5th (Highest quintile)	0.89 (0.84-0.93)	<.0001
Previous medical history: atrial fibrillation	1.23 (1.09-1.39)	0.0008
Chronic kidney disease	1.70 (1.53-1.88)	<.0001
Congestive heart failure	1.20 (1.04-1.39)	0.0107
Coronary artery disease	1.72 (1.56-1.89)	<.0001
Diabetes	4.47 (4.19-4.76)	<.0001
Hypertension	1.62 (1.56-1.69)	<.0001
Stroke	1.20 (1.06-1.36)	0.0048
Body mass index: Normal (≤25kg/m^2)	-	-
Overweight (25-30kg/m^2)	-	-
Obese (>30kg/m^2)	-	-
Missing	-	-
Resource utilization band: 0	0.27 (0.25-0.29)	<.0001
1	0.37 (0.34-0.40)	<.0001
2	0.52 (0.50-0.55)	<.0001
3	Reference	.
4	1.50 (1.43-1.57)	<.0001
5 (Highest utilization)	2.05 (1.88-2.24)	<.0001
Family physician attribute fixed parameters		
Doctor is female	1.12 (0.93-1.33)	0.2318
Years in practice (Per 5 years past 10)	1.03 (0.99-1.07)	0.2231
International medical graduate	1.10 (0.83-1.46)	0.517
Roster size: per 200 patients above 800	1.01 (0.96-1.05)	0.802
Median odds ratios		
Clinic-level median odds ratio	1.79	<.0001
Physician-level median odds ratio	2.23	<.0001

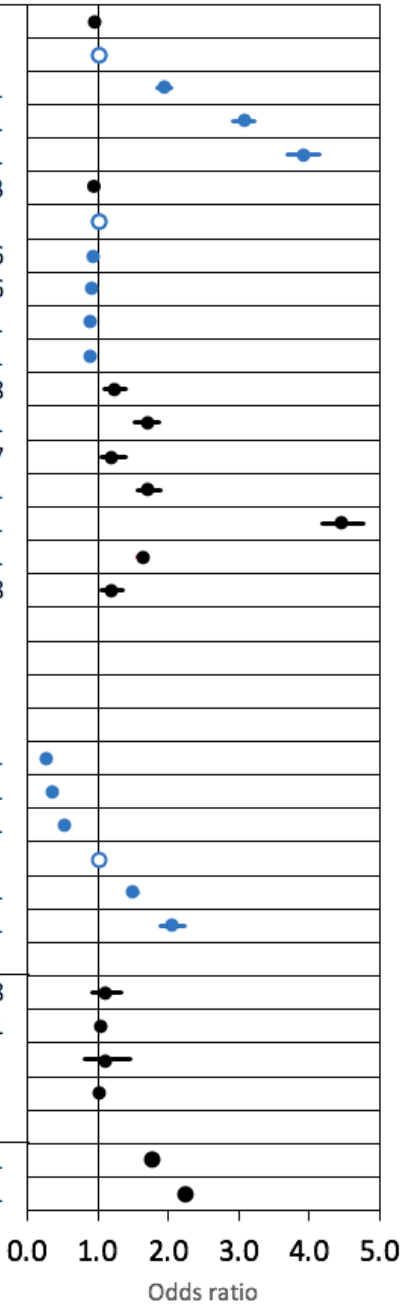


Figure 5-2 Fixed effects of patient and physician attributes on the odds ratios of a patient with a body mass index higher than 25 getting a liver enzyme test (64.3%) and the variability attributing to odds at the patient, physician and clinic levels (n = 98,687)

	Odds ratio (95%CI)	P-value
Patient attribute fixed parameters		
Female (reference male)	0.90 (0.81-1.00)	0.0531
Age (years) 18 to 34	Reference	
35 to 44	0.98 (0.71-1.36)	0.9
45 to 64	0.99 (0.72-1.35)	0.9266
65 to 84	0.89 (0.64-1.23)	0.4891
Rural (reference urban)	0.80 (0.64-0.99)	0.0427
Income quintile: 1st	Reference	
2nd	1.03 (0.87-1.22)	0.724
3rd	0.90 (0.76-1.07)	0.2451
4th	1.02 (0.86-1.20)	0.8541
5th (Highest quintile)	1.07 (0.91-1.25)	0.4326
Previous medical history: atrial fibrillation	0.94 (0.75-1.19)	0.6261
Chronic kidney disease	0.95 (0.80-1.14)	0.5945
Congestive heart failure	0.85 (0.66-1.10)	0.2288
Coronary artery disease	1.01 (0.85-1.21)	0.8717
Diabetes	Not applicable	-
Hypertension	1.00 (0.90-1.12)	0.9578
Stroke	0.78 (0.60-1.02)	0.0717
Body mass index: Normal (≤25kg/m^2)	Reference	
Overweight (25-30kg/m^2)	1.08 (0.92-1.27)	0.3256
Obese (>30kg/m^2)	1.28 (1.10-1.50)	0.0018
Missing	0.68 (0.57-0.82)	<.0001
Resource utilization band: 0	1.00 (0.70-1.42)	0.9999
1	1.05 (0.72-1.52)	0.7959
2	0.90 (0.76-1.06)	0.2124
3	Reference	-
4	1.07 (0.93-1.23)	0.3247
5 (Highest utilization)	0.90 (0.75-1.08)	0.2461
Family physician attribute fixed parameters		
Doctor is female	1.06 (0.73-1.52)	0.7637
Years in practice (Per 5 years past 10)	0.88 (0.81-0.95)	0.0016
International medical graduate	0.62 (0.36-1.09)	0.0992
Roster size: per 200 patients above 800	0.86 (0.78-0.96)	0.0043
Median odds ratios		
Clinic-level median odds ratio	2.47	<.0001
Physician-level median odds ratio	2.86	<.0001

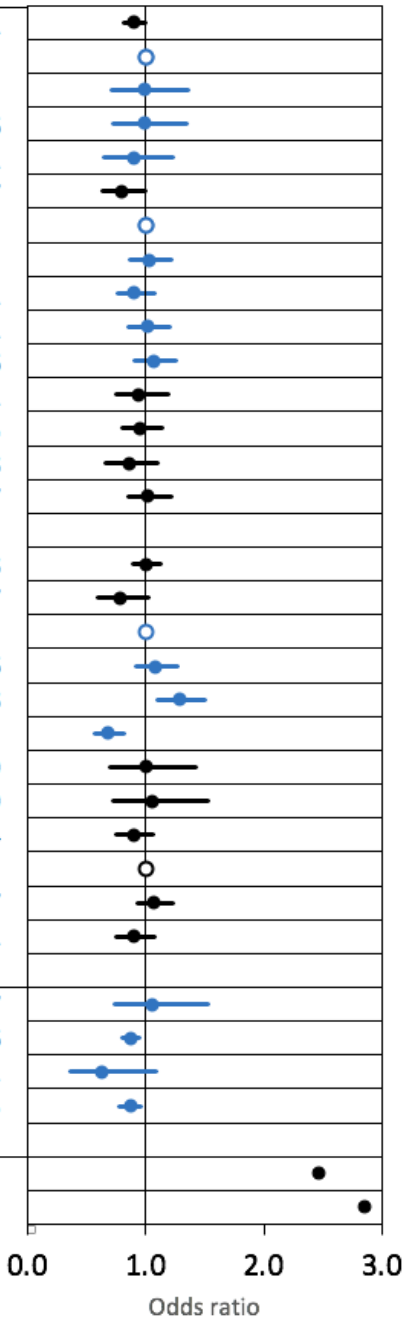


Figure 5-3 Fixed effects of patient and physician attributes on the odds ratios of a non-diabetic patient receiving a 2-hour plasma glucose oral glucose tolerance test after other tests indicating pre-diabetes (9.5%) and the variability attributing to odds at the patient, physician and clinic levels (n = 23,297)

	Odds ratio (95%CI)	P-value
Patient attribute fixed parameters		
Female (reference male)	1.09 (1.02-1.16)	0.0095
Age (years) 18 to 34	Reference	
35 to 44	0.63 (0.51-0.78)	<.0001
45 to 64	0.72 (0.59-0.88)	0.0012
65 to 84	0.77 (0.63-0.95)	0.0126
Rural (reference urban)	1.04 (0.93-1.17)	0.459
Income quintile: 1st	Reference	
2nd	0.99 (0.90-1.09)	0.898
3rd	1.03 (0.93-1.14)	0.5738
4th	0.97 (0.88-1.07)	0.5629
5th (Highest quintile)	0.95 (0.86-1.05)	0.3594
Previous medical history: atrial fibrillation	1.23 (1.09-1.39)	0.001
Chronic kidney disease	1.09 (0.99-1.19)	0.0783
Congestive heart failure	1.24 (1.11-1.39)	0.0001
Coronary artery disease	1.28 (1.17-1.39)	<.0001
Diabetes		
Hypertension	0.56 (0.52-0.60)	<.0001
Stroke	1.00 (0.88-1.13)	0.9997
Body mass index: Normal (≤25kg/m^2)	Reference	.
Overweight (25-30kg/m^2)	0.85 (0.76-0.94)	0.0028
Obese (>30kg/m^2)	0.60 (0.54-0.66)	<.0001
Missing	0.65 (0.57-0.73)	<.0001
Resource utilization band: 0	1.96 (0.79-4.83)	0.1461
1	0.98 (0.46-2.10)	0.9597
2	0.89 (0.79-1.01)	0.0691
3	Reference	.
4	1.15 (1.06-1.25)	0.0007
5 (Highest utilization)	1.13 (1.03-1.24)	0.0113
Family physician attribute fixed parameters		
Doctor is female	1.05 (0.94-1.18)	0.3682
Years in practice (Per 5 years past 10)	0.987 (0.96-1.01)	0.305
International medical graduate	1.22 (1.03-1.45)	0.0189
Roster size: per 200 patients above 800	0.98 (0.95-1.01)	0.1535
Median odds ratios		
Clinic-level median odds ratio	1.64	<.0001
Physician-level median odds ratio	1.70	<.0001

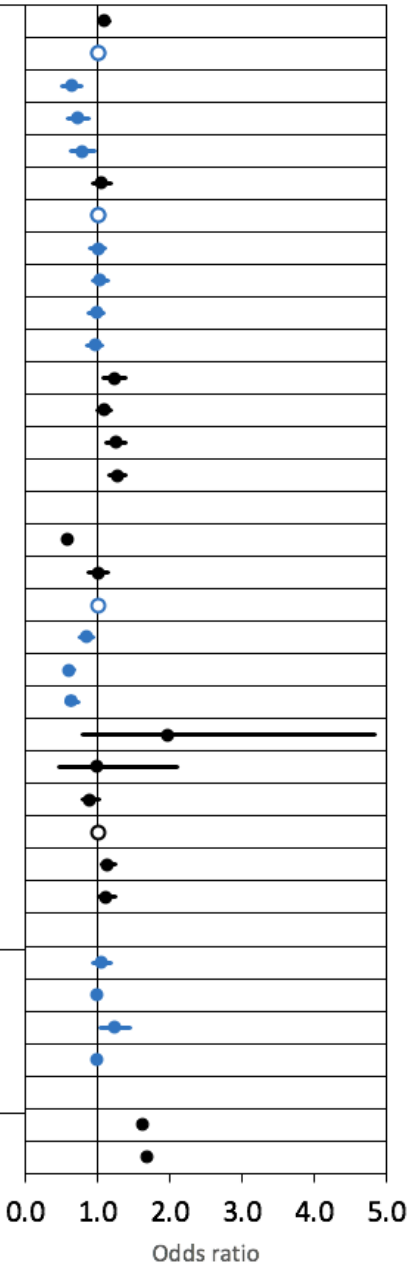


Figure 5-4 Fixed effects of patient and physician attributes on the odds ratios of a patient with diabetes having a most recent blood pressure of less than 130/80 (38.2%) and the variability attributing to odds at the patient, physician and clinic levels (n = 18,309)

	Odds ratio (95%CI)	P-value
Patient attribute fixed parameters		
Female (reference male)	0.77 (0.70-0.85)	<.0001
Age (years) 18 to 34	Reference	
35 to 44	0.69 (0.19-2.49)	0.566
45 to 64	0.73 (0.20-2.60)	0.6222
65 to 84	0.63 (0.17-2.25)	0.473
Rural (reference urban)	1.09 (0.94-1.27)	0.2424
Income quintile: 1st	Reference	
2nd	0.95 (0.83-1.09)	0.4558
3rd	0.96 (0.83-1.10)	0.5406
4th	0.88 (0.77-1.01)	0.0765
5th (Highest quintile)	0.91 (0.80-1.04)	0.1841
Previous medical history: atrial fibrillation	0.49 (0.43-0.56)	<.0001
Chronic kidney disease	1.14 (1.01-1.27)	0.0281
Congestive heart failure	1.16 (1.04-1.29)	0.0083
Coronary artery disease		
Diabetes	1.28 (1.17-1.41)	<.0001
Hypertension	1.26 (1.15-1.37)	<.0001
Stroke	1.93 (1.68-2.22)	<.0001
Body mass index: Normal (≤25kg/m^2)	Reference	.
Overweight (25-30kg/m^2)	1.02 (0.89-1.17)	0.798
Obese (>30kg/m^2)	1.02 (0.89-1.17)	0.7818
Missing	0.89 (0.77-1.03)	0.1272
Resource utilization band: 0	0.20 (0.11-0.38)	<.0001
1	0.58 (0.27-1.29)	0.1827
2	0.70 (0.54-0.89)	0.0044
3	Reference	.
4	1.25 (1.13-1.39)	<.0001
5 (Highest utilization)	1.47 (1.32-1.64)	<.0001
Family physician attribute fixed parameters		
Doctor is female	0.99 (0.84-1.17)	0.9149
Years in practice (Per 5 years past 10)	0.97 (0.93-1.00)	0.0601
International medical graduate	0.98 (0.76-1.26)	0.8474
Roster size: per 200 patients above 800	0.95 (0.91-0.98)	0.0064
Median odds ratios		
Clinic-level median odds ratio	1.71	<.0001
Physician-level median odds ratio	1.94	<.0001

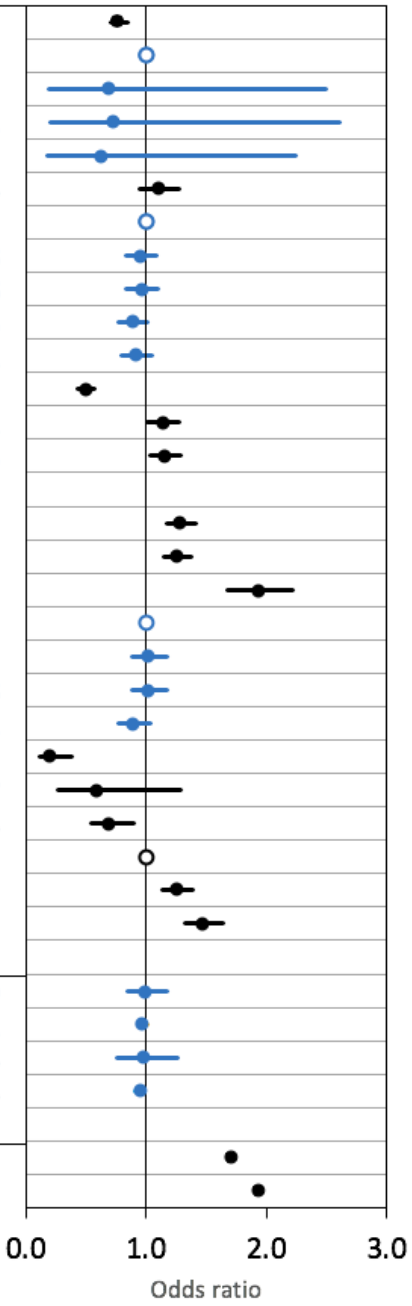


Figure 5-5 Fixed effects of patient and physician attributes on the odds ratios of a patient with coronary artery disease receiving antiplatelet therapy (47.8%) and the variability attributing to odds at the patient, physician and clinic levels (n = 10,327)

Chapter 6

Understanding the challenges and barriers to implementing quality improvement tools: a qualitative study

The purpose of this chapter is to answer the question, "what are the barriers to, and facilitators for, the adoption of EMR-embedded tools designed to increase guideline-adherence in primary care at the provider and organizational level?"

EMR-based tools can be developed for targeted quality improvement in chronic disease management. However, without actual uptake and use of the tools, they are ineffective at changing physician practice. Chapter 6 sought to gain an understanding of EMR tool implementation challenges in primary care, with the goal of applying the lessons from this chapter in future EMR tool development and implementation.

The objectives of this chapter are to:

1. Identify the potential barriers and facilitators to adopting EMR tools used for quality improvement in primary care;

2. Evaluate sociotechnical aspects of a quality improvement tool targeting chronic kidney disease management that is embedded in the EMRs through qualitative methods;

A modified version of Chapter 6 was submitted to the Ontario Renal Network as an internal evaluative report on the chronic kidney disease tools discussed.

6.1 Abstract

Background: We implemented a set of clinical decision support tools embedded in the electronic medical record (EMR) and performance reports to help improve primary care management of chronic kidney disease (CKD) as part of a pragmatic randomized controlled trial. There was limited uptake of the tools despite multiple efforts to engage the physician participants. The objective of this study was to understand and identify the barriers that family physicians face in implementing decision support tools to improve chronic disease care.

Methods: We conducted semi-structured interviews and framework analysis based on normalization process theory to obtain a better understanding of physicians' experience, perspectives and opinions surrounding the uptake of quality improvement tools embedded in primary care EMR for the management of chronic disease, and performance feedback reports.

Results: Twelve study physicians were interviewed for an average of 39 minutes each. One physician had used the CKD tools, two had seen the tools but did not install or use the tools, and nine did not recall seeing the tools. Four major thematic barriers to implementation of EMR-based tools emerged, including misalignment between the tool and physicians' priorities around chronic disease management; technological barriers; organizational barriers; and individual barriers to routine use of the tools.

Interpretation: In order to have uptake of a new quality improvement tool, it is important to understand the physicians' competing priorities, and align the tool to be compatible with the physician's approach to clinical management (e.g. providing unique person-centred care). Changing attitudes and beliefs regarding the importance of the detection and management of some chronic diseases can be a critical barrier. Improved attention to design, planning, provision of technical support and capacity building may reduce technological barriers. Organizational barriers including human resources or infrastructure availability to the physicians' practice must be considered. Clinical champions on-site to lead their peers in the implementation process is vital. Limited time was one of the biggest challenges, and tools must be designed to have high utility and reduce additional workload on the physician. Future research in quality improvement implementation in primary care should methodically test how to best address the issues identified in this study in order to achieve successful adoption and implementation.

6.2 Introduction

Primary care clinics around Ontario are currently providing electronic medical record (EMR) data to the Electronic Medical Record Administrative data Linked Database (EMRALD®) at the Institute for Clinical Evaluative Sciences (ICES). Studying this data has identified that primary care physicians' management of chronic kidney disease (CKD) has room for improvement.[124] A pragmatic randomized controlled trial was conducted to assess whether a set of clinical decision support tools embedded in the EMR and performance reports based on quality indicators could help improve primary care management of CKD.[226] Preliminary results of the trial showed limited uptake of the CKD decision support and quality improvement tools among the participating physicians.

The limited uptake is problematic for evaluating the effectiveness of the CKD tools, but provides an opportunity to better understand the underlying cause of why physicians are resistant to using new tools that could potentially improve quality of care for their patients.

The objective of this study was to identify the barriers that family physicians face in implementing decision support tools to improve chronic disease management. Qualitative methods were used to obtain a better understanding of physicians' experience, perspectives and opinions surrounding management of CKD, chronic disease management, the uptake of quality improvement tools embedded in primary care EMR and performance feedback reports.

6.3 Methods

This evaluative qualitative study was embedded within a larger pragmatic cluster-randomized trial in which family physician participants received performance feedback reports (System for Audit and Feedback or SAFIRE) and a toolkit of point-of-care tools that embed in the EMR (consisting of a flowsheet, a patient handout, and set of reminders). The protocol for the overall project has been previously reported.[226] The study was approved by the Sunnybrook Research Ethics Board.

6.3.1 Tools made available for improving quality of chronic kidney disease management

The set of tools and resources related to CKD management offered to the physicians in the trial consisted of the following, and are further described in detail in the published protocol[226]:

1. EMR-based clinical decision support flowsheet
2. Patient education handout
3. EMR-based clinical reminders
4. System for Audit and Feedback to Improve caRE (SAFIRE) web-based feedback on quality indicator performance for CKD

The EMR-based clinical decision support flowsheet (Figure G-1) was a custom form that could be embedded into PS Suite EMR. This custom form was based on the Ontario Renal Network's Kidney Wise clinical algorithm which could generate the appropriate pathway of care based on the patient's estimated glomerular filtration rate (eGFR) or albumin to creatinine ratio (ACR).

The patient handout (Figure G-2) was aimed at patients who were newly diagnosed with CKD and consisted of a personalized report that could be auto-populated and printed based on the patient's data in the EMR, such as their latest laboratory test results. This form described the function of the kidneys, what it means to have CKD, recommendations to lifestyle modifications (around diet, exercise, and smoking), and recommendations on medical changes they could discuss with their physician.

The EMR-based clinical reminders **(**Figure G-4**)** consisted of rules that could be installed in the EMR based on CKD quality of care indicators. The reminders would pop up based on the most recent eGFR or ACR values and the rules could be modified by physicians to account for any differences in EMR nomenclature related to different diseases and laboratory test results.

SAFIRE **(**Figure G-4Figure G-7) is a web-based feedback platform available to all physicians who contribute their data to EMRALD®. It is available online through a secure website which provides confidential, individualized performance reports to physicians regarding their quality of care for patients with certain chronic diseases (e.g. hypertension, diabetes, and ischemic heart disease). The reports were based on audit-and-feedback reports based on CKD quality of care indicators (Appendix H) from two perspectives: 'At-target' graphs **(**Figure G-4**)** showing how

many of the physician's patients are meeting guideline-based targets, and 'high risk' graphs **(**Figure G-5Figure G-4**)** showing how many of the physician's patients were well beyond targets and at highest risk for adverse events and should be prioritized for addressing. SAFIRE reports on CKD care included physician's performance in comparison with the top 10% of other EMRALD physicians; their performance in comparison with the top 10% of colleagues within their own practice site (for physicians that practice in a group of 3 or more); their clinic performance compared with other participating EMRALD® clinics (Figure G-6); and changes in their performance over time. Physicians were also able to download a list of their patients and import it into their EMR system to see the details of the individual patients' charts within the EMR (Figure G-7). Physicians in the trial's intervention group were notified by email when their reports were available to be viewed.

6.3.2 Recruitment strategy

Purposeful sampling was used to capture diverse viewpoints and representation from participating physicians. Both physicians who have used the CKD tools and have never seen or used the tools were eligible for the study. We recruited participants by inviting family physicians to participate in the study via personalized email, offering an honorarium of $50 in the form of a gift card. Physicians were interviewed until data saturation was reached (initially estimated to be between 10 and 15 physicians). To recruit an adequate number of participants, reminder and follow-up emails were sent out to nonresponding physician, and interviews were set up to be at a date and time of their choice.

6.3.3 Interview

Semi-structured, individual interviews were conducted by a single interviewer and reviewed by a note-taker to ensure a consistency in data collection and flow of questions. Interviews occurred over a period of 40 days after the trial end. The interview was guided by a set of probing questions informed by clinical and research experience of the research team and on concepts from Normalization Process Theory (NPT), a socio-behavioural theory on the adoption and routine use of new innovations[79]. The probing questions sought to draw out physicians' perception of decision support tools in the EMR, their understanding of the tool (coherence), their routine EMR use, availability of support for quality improvement initiatives or EMR tools in their clinic, feedback on the tools and other factors that may pose a barrier to installing and using the CKD tools. If the physicians did not use the CKD tools, we asked them about their

experience with using other quality improvement tools embedded in the EMR. An interview guide is available in Appendix F.

Each interview was audio-recorded with the participants' consent and lasted about 30 minutes over web-conferencing software. The recordings of the interviews were used for transcription and reference for data analysis. We collected information on clinical characteristics to gain a better understanding of the physician's practice (i.e. number of years in family medicine, number of years at their current practice, number of years using the EMR, size of their clinic, size of their patient roster, information about the make-up of their clinic staff including other clinicians, support staff and IT services they received). We showed a demonstration of the CKD tools being studied and sent screenshots ahead of time to aid in the interview process and to draw out their thoughts on hypothetical adoption of those tools in their practice if they had not installed or used the tools.

6.3.4 Analysis

All interviews were transcribed and imported into *NVivo* software. The interviewer and note-taker coded the transcripts independently using the framework approach[227] directed by concepts from NPT (coherence, cognitive participation, collective action, and reflexive monitoring), with the addition of any themes arising from an inductive approach[228] if they did not fit the NPT framework. The coders read the transcript and coded quotes that appeared to represent new or existing themes, with the goal of identifying and understanding the issues that were present in the uptake of the tool. The coding of the first three interviews were compared between the first and second coders to ensure coding consistency and quality. Any discrepancies in coding were discussed with a third reviewer to gain agreement and all differences were resolved. The codes were further categorized into an index of themes and concepts, ideas or experiences related to CKD management or EMR use. These themes were organized into relational hierarchies and discussed with the research team to gain agreement on key initial findings. The results were reviewed iteratively by the whole research team and organized into major themes.

6.4 Results

6.4.1 Participant characteristics

Twelve physicians in the intervention arm of the RCT were interviewed for this study before reaching data saturation (until no new codes were found in the interview). Three additional physicians who initially agreed to the interview later dropped out of the study citing 'lack of time'. The interviews lasted on average for 39 minutes, ranging from 28 minutes to 55 minutes. The participants varied with respect to sex, years of experience, size of practice, rurality and years using the EMR. The interviewed physicians had been practicing family medicine on average for 22 years (range of 6 to 45 years). The interviewed participants' characteristics are presented in Table 1. One out of the twelve physician had previously installed and used the tools on a regular basis. Two physicians had seen the invitation to use the tools but never installed them. The remaining nine did not recall seeing the CKD tools before. Five of the physicians interviewed described routinely using other advanced functions on their EMR and could be classified as advanced or super-users. Two physicians described their limited use of their EMR and the remaining five physicians showed average usage of advanced EMR functions.

6.4.2 Findings

Analysis of the coded interviews generated four major themes related to the challenges and barriers of implementing CKD tools:

i) alignment between physicians' priorities around CKD management;

ii) technological barriers;

iii) organizational barriers;

iv) individual barriers to the routine use of CKD tools

While NPT concepts were initially used to guide the interview questions and frame the research, we found that a majority of the participants did not implement the CKD tools prior to the interviews, nor did they embed the tools in their routine work. As such, we were unable to fully utilize NPT[79] to analyze the barriers to the embedding and routine use of CKD tools. We made our interview questions less restrictive to gather physicians' experiences with other quality

improvement tools which were embedded in their EMRs, and not solely their experience with the CKD tools from the above-mentioned trial.

As posited by May and Finch[79], we were able to use NPT to validate from our participants the assertion that embedding new practices (in this case, the tools provided to physicians) is dependent on socially patterned implementation work and actors investing in the new practice (e.g. a clinical champion acts as a proponent of a new practice and energizes the adoption and implementation of quality improvement tools). We used thematic analysis to code our data as it did not adequately fit the breadth of NPT concepts and mechanisms.

Table 2 provides a summary of findings mapped to the four themes surrounding. Each theme is described in detail below.

6.4.2.1 Theme 1: Perceived alignment of priorities and CKD management.

The first theme that emerged as a barrier to uptake of the tools was misalignment between the physician's desired CKD management practices and perception of the tool's purpose, objective and utility.

Primary care physicians must juggle many challenging and competing priorities, especially when it comes to managing patients with multiple morbidities. Physicians expressed that they find it important to provide comprehensive care that meets individual patient needs in primary care, and showed a degree of reluctance and skepticism to following disease-specific guidelines that approach the management of CKD from a disease-specific perspective or with a 'specialist's lens'. Physicians also perceived CKD management to be less actionable (i.e. reaching a treatment target, improving the condition) and felt the management relied more on patient education and preventive measures that are not fully in their control, especially when compounded by comorbidities and changing guidelines.

Without placing high priority on CKD-specific management and a good compatibility between the tools and their desired CKD management, physicians were not likely to have interest in installing and using the CKD tools. Physicians who used the tools or were interested in using it made CKD a specific priority in their practice. This was contrasted by the majority of physicians who were not as interested in the tools and saw CKD as only a small fraction of their practice that was intertwined with higher priority conditions like diabetes and hypertension.

It was clear that physicians must agree with the tool's purpose, objective, and utility before deciding to use it. If the tool does not fit well with the physician's preference or workflow, or is perceived to be a hindrance on their clinical judgement and autonomy, the tool is unlikely to be adopted. Quotations from the interviewed participants regarding their perceived alignment of priorities and attitudes toward CKD management are presented in Box 1.

Box 1 Quotations regarding physicians' perceived alignment of their priorities and CKD management

- "Well, the use of an isolated tool like this tool would be great if all they had was reduced eGFR. For that one patient, where everything else is normal but their eGFR is reduced, this is helpful. But where it's multifactorial…this would be one issue out of say, four, because they're diabetic, hypertensive, they smoke, they have COPD, by the way they're depressed, this then becomes less helpful because you're focusing on one issue and it is a piece of their puzzle."
- "There is no question that this is one of the areas that we don't treat as aggressively as we should. Probably because there is lower awareness…"
- "To be honest, I don't think physicians are cued into the fact of how serious it is."
- "And because it's one of those things that sometimes the data just kind of gets lost. Unlike diabetes where everyone knows what the diagnosing criteria are, CKD is more of an ongoing issue that is getting worse where you don't hit this magic number and now you have this, and you should do that."
- "These algorithms, go from this box to this box, 'do this, this, this, this, and then you're done'? Um, it's not really the way that I kind of see what we're supposed to be doing. Again, like my comment before about the guideline oriented education, that kind of approach to medicine has never really made that much – at the end of the day, I think in ten years, everyone is going to say 'oh yeah, isn't that funny what we did back then, and look what we do now'."

6.4.2.2 Theme 2: Technological Barriers.

Technical challenges and efforts related to EMR use remain real barriers to implementing new tools. Depending on the individual physician (innovators, early adopters, or laggards),[229] they may be unfamiliar with or resistant to the technical aspects involved in installing, learning, and

using the tools. This can be further amplified by resource limitations, such technical capability or availability of staff with the skills necessary to adopt the tools.

Although the majority of physicians were already routinely using EMR custom forms, flow sheets, reminders and built-in decision support tools, they cited many challenges to using their EMRs optimally. This included the lack of standard use among their colleagues; unfamiliarity with advanced features or installation of custom forms or reminders; limited technical capability among physicians (themselves or their colleagues); and the high level of effort required to use EMRs for quality improvement initiatives.

There was large variation in how the EMRs were used in the clinics. In fact, physicians and their teams found many workarounds and creative workflows to suit their needs even if the EMR functions were not intended to be used in the manner they created. With their existing personal workflows, they may have found it unnecessary to add on additional tools, or found it more challenging to adapt to a different way of using the EMR. This is reflective of the overall desire for good technology that could facilitate and optimize their clinical management despite all the current issues. Physicians were open to the idea of new technology and new tools so long as they were aligned with what they envision a useful tool to be, helped them with their work process and made important information easier to access.

These challenges and barriers can be mitigated or worsened by the tools' usability. In order to be adopted, the tools must be easy to use to lower the barrier to access. Physicians preferred tools to be user friendly, visually uncluttered and as simple to use as possible. Quotations from participants regarding technological barriers are presented in Box 2.

Box 2 Quotations regarding technological barriers

- "But the problem with the reminders I find is, every now and then they get broken, for whatever reason"
- "To me I think the deterrent is the work of doing that, I'm not the techy one – like I said, because I'm not the techy one – make it clear, like 'this is exactly what you need to do' for people that may not know how to install things on the computer"
- "It's the balance between how much work I have to do and how useful it's going to be"

6.4.2.3 Theme 3: Organizational Barriers.

Limited resources: Limited IT resources were a barrier for many physicians, who frequently depended on staff members who happened to be the most technologically savvy to deal with any IT issues that arose. Many did not have a dedicated IT manager or support staff, or shared the IT resources with several other offices and across thousands of patients.

EMR resource sharing was common in order to lower the high cost of EMR server fees. Sharing EMR servers means that any tools installed on the EMR would have to be shared across all users sharing the servers. Cost-sharing this resource limits the EMR space available for the user as well as the autonomy to use the EMRs as they wish. The addition of different clinics to a server increases the variability of EMR use, augmenting the challenges associated with maintaining standard structure in the EMR (within the notes, patient history, reminders, et cetera).

Governance structures for IT or quality improvement initiatives were common in such cases in order to achieve consensus on EMR management, to minimize variation, and reduce redundancy in the servers (e.g. redundancy of commonly used EMR forms). This also ensured that there are structures, protocols, or processes within the clinic in introducing new initiatives, implementing guidelines, or making changes to the EMR tools within the clinic.

Box 3 Quotations regarding organizational barriers including limited resources and clinical leadership.

- "The electronic medical records sits on a server, so we have a locally hosted server, so not too uncommon, it's quite cost prohibitive for each physician to have their own connection to *Telus*, um, so um yeah, because it's all on the same server up until now, um, everything from stamps, custom forms, reminders, toolbars, all of it, has to be clinic-wide"

- "I have found it challenging for the last few years to get on the same page with the other physicians for any of us to take the time to make sure, you know, I'd love to go and delete a bunch of reminders I don't use, but it requires a meeting with other physicians in order to decide, are you using that or not using that, and can we just delete that? Likewise, for stamps and custom forms, uh, it's... it's been a challenge"

- "[It's a] slow process, you know, trying to get everybody first to agree upon 'this is the standard of care' and then, you know, then agreeing upon 'these are the tools that will help us implement the standard of care.'"

- "Typically, you ask your secretary. It's not that she enjoys it or it's a special job, so she's better than others, so she has a bit more…again...it's such a small clinic, and we don't have someone assigned to IT.

- "there's a little bit of umm, politics isn't the right word, but something like it, um, when deciding which items to focus on, because there are so many possible issues or decision support tools or, or, problems to deal with. There's an individual who is a champion at our clinic right now so whatever they are pushing at that moment is what's getting on our EMR right now."

6.4.2.4 Theme 4: Individual barriers

Clinical leadership: In order for a new quality improvement initiative or EMR tool to be brought about, a clinical champion and quality improvement lead was critical for successful implementation. In places where a structure existed, a clinical lead must bring up the tools, seek

consensus from the members of the team that share the EMR, and agree on the utility of the tool across the clinic before it can be installed clinic-wide. In clinics and teams where EMR resources are shared, this is a lengthy, but necessary process that also requires strong leadership, communication and organization. Getting early clinical championing can be instrumental in a successful implementation. Physicians mentioned that the number of new initiatives that can be introduced at any given time is limited due to finite resources and time available, but regular meetings are in place to discuss any issues arising. There must be a champion on the team who is invested in the project and pushes for its implementation and adoption.

Quotations from participants around organizational barriers including limited resources and clinical leadership are presented in Box 3.

Many of the participants did not recall ever seeing the tools or emails sent out to install the tools When prompted to consider why they never installed the tools despite seeing the notification or emails, the most frequent response was due to limited time. Physicians also lost interest due to experiencing initial barriers, such as trouble remembering the sign in details and password. Due to competing priorities, limited time, work and having too many things to attend to, communication through emails may fall to the wayside. Many physicians expressed having an overload of tools to use, felt overextended and overstretched from everything they have to do as family physicians.

Routinely used tools like those used for diabetes management or well-child visits were more likely to be used due to financial incentives and perceived high utility. Incentivizing physicians and changing norms over time can be ways to increase adoption of new innovations.

Clinics that had allied health support or used a team-based approach to quality improvement initiatives had the ability to delegate the job of reviewing quality improvement review such as reminders check of SAFIRE results to their physician assistant or nurse if available. Some physicians saw this delegation as a solution to the limited time available to family physicians and felt that they were not able to take on some of the suggested quality improvement initiatives. Quotations from participants regarding individual barriers are presented in Box 4.

Box 4 Quotations regarding individual barriers to uptake CKD tools

- "Like everything in primary care right now, you're over, over-extended and over-taxed and you do your best with the time and the resources that you have."
- "I don't have time and if I don't have time to deal with it, it gets lost"
- "I mean, as a family doctor, you get an incentive. You get a bonus to have all your diabetes patients seen at regular intervals. So I think diabetes is managed probably a lot better than chronic kidney disease just for that reason. You get bonuses for your patients being cared for regularly, so everyone is very on top of diabetes. We make sure that all our diabetes patients are accounted for, and we make sure that they all come regularly. So I think that it's done very well for diabetes, and probably not for chronic kidney disease."

6.4.2.5 Feedback on the CKD tools

In addition to the themes that emerged, we were also obtained direct feedback about the CKD tools themselves. There were both enthusiastic and negative responses to the tools that were demonstrated during the interview. Two physicians already used a paper copy of the CKD flowsheet on a regular basis at their clinic and were enthusiastic about the CKD tool. Six of the twelve interviewed participants felt that the at least one of the tools could be useful and requested access to the tools to install or use at their clinic.

Flowsheet (Figure G-1**):** For the CKD algorithm flowsheet, positive feedback included finding it helpful to teach residents, and as a reference for managing trickier, more moderate stages of CKD. Physicians would feel less reluctant to use the tool if it was visually less cluttered and simplified, easier to read and if it could integrate well with the whole clinical encounter.

Patient handout (Figure G-2**)**: The majority of the physicians found the patient handout useful for providing to patients as an educational resource. Physicians who already had similar resources to provide or preferred a more comprehensive approach to patient educational (e.g. not specific to CKD) were more reluctant to use the tool.

Reminders (Figure G-4**):** Physicians saw high utility in looking for patients that may have fallen through the cracks and have not had a repeat test that they should have gotten. Many physicians cited reminder fatigue as a concern and the importance of ensuring that reminders are valid, useful and up to date.

SAFIRE (System for Audit and Feedback) (Figure G-4Figure G-7**):** The majority of physicians interviewed (except two) found SAFIRE to contain useful information, particularly for research, comparing their performance and as a source of motivation to improve. The most frequently stated drawback was requiring a login (as opposed to having the results sent to them and automatically embedded into their EMR), frequency of the password changes required to access their data, and visual overload of information.

6.5 Discussion

Our qualitative study findings identified four major thematic barriers to adoption of quality improvement tools for chronic disease management (Table **6-2**). This included physicians' priorities and attitudes toward chronic disease management; technological barriers; organizational challenges such as limited resources and clinical championship to push for quality improvement; and limited time for individual physicians who feel overburdened by many responsibilities and other priorities that compete for their attention.

These identified barriers were in line with previously identified barriers to the adoption and implementation of e-health technologies as summarized in a scoping review by de Grood et al.[230] and systematic review of barriers and facilitators to clinical decision support systems adoption by Devaraj et al.[231] De Grood reviewed 74 articles and identified seven barriers to e-health technology adoption and implementation, namely: design and technical concerns, privacy and security concerns, cost and liability issues, productivity, patient and physician interaction, lack of time and workload, and lastly, threatened clinical autonomy.[230] The facilitators identified were pre-analysis of data, proof of utility, training and support, and ownership and size of practice.[230] Devaraj et al. [231] examined twenty-six publications and used the Unified Theory of Acceptance and Use of Technology (UTAUT) model to classify their findings under the four dimensions of performance expectancy, effort expectancy, social influence and facilitating conditions.

Similar to articles reviewed by de Grood,[230,232–247] we found usability issues created design and technical concerns were a barrier to uptake of our tools. We found limited concerns surrounding privacy and security for our tools, with the exception that the password reset requirements on the Audit and Feedback system put in place for patient privacy and security reasons were a hindrance to system usability and accessibility. This barrier concerning privacy and security may have been reduced due to the users' confidence in the measures taken to protect confidentiality, research ethics and patient privacy policy at the organization conducting the research, or due to the fact that all users have already adopted EMRs at their clinic and look at e-health technology more favourably than non-users of EMRs. Cost and liability issues were not significant issues for our participants except that opportunity costs and competing costs were considered for other disease conditions that had higher financial incentives for improved management (i.e. financial incentives for diabetes care). Similar to findings identified in the literature[234,235,248–260] by de Grood et al.[230] and Devaraj et al.,[231] our participants had concerns about lack of time and workload and the impact of time lost on their productivity. Some participants were also concerned about threatened clinical autonomy and their agreement with the intention of the tool versus their clinical judgement which was also observed elsewhere.[233,261] We found that scientific evidence and proof of utility which were identified as facilitators in previous studies[240,241,247,257,259,262,263] were also important to our participants as were training and support for adoption of the technology, preferably on-site. Similar to findings summarized by Devaraj et al,[231] we found parallels between the dimensions identified in the UTAUT model and NPT model, surrounding concerns around lack of time or time constraints, lack of knowledge of system or content, lack of agreement with the system and physician attitude toward the system. Our findings had degree of barriers around lack of awareness and existence of the tools in question.

We received both positive and negative feedback about the CKD-specific tools but in many cases verified the usefulness of the tools in the right context if they had been implemented and adopted. It is critical to understand the organizational processes that are in place at each clinic to adopt quality improvement initiatives, especially if it requires integration into the EMR and approval from a governance structure. There must be buy-in and adoption from a clinician who believes in the evidence and importance of the quality improvement, and is willing to

communicate them to his or her colleagues in order to get agreement to use the tools (a clinical champion).

Further, it is important to understand the sociotechnical environment of the organization of interest, including any technical or resource limitations. Not every clinic setting will have the resources in place to know how some to install or use the tools. They may require more invested technical support in order to lower the barriers to installation and use; and an offer of a tutorial or walk-through may be enough to get sustainable uptake. Financial barriers also pose a challenge, and some practices may be looking to avoid incurring fees for assistance with tool installation, which may be a hindrance to certain clinics.

While the tools that we developed were not widely adopted by the participants, we were able to identify challenges and barriers have the potential to be mitigated in future projects. Potential mitigation strategies for addressing these barriers in future research are presented in Table **6-2**. In order to have uptake of a new quality improvement tool, it is important to understand primary care physicians' priorities, including competing priorities, and align the tool in question to be compatible with the physician's approach to clinical management (providing unique person-centred care). All technological barriers must be reduced as much as possible, through design, planning, and provision of technical support and capacity building on-site. Organizational barriers and contexts must be carefully considered before implementation, including human resources or infrastructure availability to the physicians' practice. It will be essential to have a clinical champion on-site to lead their peers in the implementation process. Lastly, limited time is a big challenge to implementation, thus the tool must be designed to have high utility and aim to not add to the workload of the physician.

6.5.1 Study Limitations

Our study has a few limitations. First, we interviewed only volunteering physicians who responded to our emails and were willing to participate in the study. EMRALD® participants overall are skewed to be more likely to practice in Family Health Teams, which have different resources, processes, mandates and practice than solo practices. Findings from the participants may not be representative of all Ontario physicians. We were, however, able to recruit physicians who are in smaller or rural practices to provided more diverse representation of physician's experience with respect to CKD management and EMR use.

In addition, the interviews were conducted over web-conferencing and telephone, which limited the interviewer's ability to read body language and non-verbal cues that would be present in an in-person interview to guide the direction of the interview. Finally, as the interviews were conducted with physicians only, we may be missing important information that can be provided by other clinic support staff, physician assistants, nurse practitioners, or administrative staff that also interact with the use and implementation of decision support/quality improvement tools.

6.6 Conclusion

Family physicians participating in our larger cluster-randomized trial did not adopt the quality improvement tools for CKD management despite multiple efforts to engage them to use the tools. Changing attitudes and beliefs regarding the importance of the detection and management of chronic diseases like CKD is an important barrier that needs to be overcome. Even if family physicians are motivated to use quality improvement tools and have championed other initiatives in the past, the barriers identified in this study must be lowered in order to achieve successful implementation. Future research in quality improvement implementation in primary care should methodically test how to best address the issues identified in this study in order to achieve successful adoption and implementation.

6.7 Tables

Table 6-1 Characteristics of interviewed physicians (n=12)

Participant characteristics	**Interview participants,** N (%)
Physician's sex	
Male	9 (75%)
Female	3 (25%)
Number of years in practice	
<10 years	2 (17%)
11-20 years	4 (33%)
22-30 years	3 (25%)
30+ years	3 (25%)
Physician's roster size	
<1000	4 (33%)
1000-1500	6 (50%)
>1500	2 (17%)
Number of physicians in the clinic	
1-4	4 (33%)
5-9	3 (25%)
10-25	3 (25%)
25+	2 (17%)
Clinic's patient roster size	
<5000	5 (42%)
5000-10000	3 (25%)
10000-20000	2 (17%)
>20,000	2 (17%)
Rurality of the clinic location	
Rural	2 (17%)
Suburban	3 (25%)
Urban	7 (58%)
Years using EMR	
<10 years	3 (25%)
10-14 years	7 (58%)
15+ years	2 (17%)
Has dedicated IT support? (Excluding contracted IT support)	
Yes: 6	6 (50%)
No: 6	6 (50%)

Table 6-2 Identified barriers and potential mitigation strategies for implementing quality improvement tools for chronic disease management in primary care

Barriers	**Potential mitigation strategy to be considered in future research**
1. Perceived alignment of priorities around chronic disease management	Assess and align with primary care physician priorities, incorporate holistic measures and approach to chronic disease management and quality improvement
2. Technological barriers	Provide support for technical aspects required to adopt the quality improvement tool and plan for capacity-building. Limit barriers to use by improving usability and access to the tools
3. Organizational barriers	Understand organizational structure at the primary site and gain buy-in from clinical champions early on in implementation
4. Individual barriers	Design and develop tools with the final user in mind, optimize utility and ease of use for the user.

Chapter 7

Discussion

The purpose of this chapter is to:

1. Summarize the five original studies in this thesis
2. Synthesize the findings and discuss the main points of the studies
3. Discuss the strengths and limitations of the studies
4. Discuss the implications for clinical practice, health policy and research
5. Describe future research directions

7.1 Summary of research

The overarching goal of this thesis was to examine the use of electronic medical records in primary care settings in Ontario for measuring and improving the quality of chronic disease management. The preceding chapters demonstrated possibilities in secondary use of primary care EMR data for health services research. They provided insights on the use of advanced EMR features to improve the quality of chronic disease management. Specifically, the five studies:

- developed a validated method for identifying patients with COPD, a complex chronic disease, within EMR data;
- used EMR data to assess whether patients were receiving recommended cardiovascular care based on measurable recommendations from clinical guidelines;
- used EMR data to assess whether patients with COPD are receiving recommended care based on existing quality indicators;
- used EMR data linked with administrative data to explore patterns of variation in practice and to identify patient and physician factors that correlate with the odds of receiving guideline-adherent care; and
- examined factors that contribute to the successful adoption and uptake of EMR tools for chronic disease quality improvement by primary care physicians.

The research presented in this thesis demonstrate that routine data collected in EMRs can be leveraged to provide valuable information applicable to public health surveillance, health services research and health informatics research. These studies also revealed strengths and limitations of using EMRs as a data source and platform for health services research to study quality of care for chronic disease management in primary care.

In answering the original research question, "can EMRs be used to measure and improve quality of chronic disease management in primary care practices in Ontario?" the following results were found for each of the four questions:

> *1. Can EMRs be used to accurately identify patients with chronic diseases such as chronic obstructive pulmonary disease (COPD)?*

Identifying patients with a specific chronic condition is necessary to study how patients with the condition are being cared for in the health care system. It is also necessary for targeted quality improvement initiatives. Chapter 2 detailed how EMR data was used for identifying COPD, a complex respiratory illness that is a growing concern worldwide. This chapter described a validation study which used primary care EMR data to develop an algorithm for identifying patients with physician-diagnosed COPD in a primary care setting. The algorithm was compared against manual abstraction of the patient charts and showed high performance in accurately identifying patients with COPD as marked by a high positive predictive value. This study suggested that EMRs can be a valuable source of data for identifying patients with complex disorders or chronic diseases that may otherwise be challenging to identify in the general population. However, as the algorithm was not perfect, there are considerations to take into account when interpreting the results of any research that use EMR data to create case-definitions.

2. Can EMR systems measure primary care physicians' adherence to clinical practice guidelines for patients with COPD or cardiovascular disease?

Measuring quality indicators helps gain an understanding of current healthcare practices and evaluates if improvements are taking place. Quality indicators, based on clinical guidelines, are a way to assess the extent to which recommended care is taking place and act as markers of health care quality. Chapters 3 and 4 demonstrated that primary care EMR data could be used to measure primary care physicians' adherence to some clinical practice guideline recommendations and to measure performance based on clinical quality indicators. This was dependent on the type of quality indicator, the required information and if it was routinely recorded in the EMR. We identified a number of considerations when measuring quality of care using routinely collected EMR data, including the importance of timeline specification and considering what clinical details are standardized in data recording practice and measurable in the EMR. Certain aspects of care may not be well evaluated with EMR data, including information surrounding patient lifestyle, diet, physical exercise, and others, as further described within the chapters and in the limitations section below. These studies also uncovered potential gaps in the care received by patients compared to the recommended care for CVD and COPD.

Chapter 3 described the development of measurable quality indicators based on existing clinical guidelines on cardiovascular health. Recommendations from the 2014 Canadian Cardiovascular Harmonized Guideline Endeavour (C-CHANGE) were developed into quality indicators if they consisted of clinical information that was recorded in the EMRs. These indicators were measured within the population in EMRALD® to assess the proportion of patients receiving guideline adherent care. Twenty-three indicators on cardiovascular risk assessment, screening, diagnostic testing, treatment targets and pharmacotherapy could be measured out of a total of 74. Recommendations related to diet and risk stratification were not measured due to limitations on what EMR data could be assessed. Among the measured quality indicators, we found large variation in guideline adherence, with relatively high adherence to prescription of antihypertensive therapies and low adherence in certain diabetes screening tests.

Chapter 4 assessed quality of care received by patients with COPD in primary care settings, in a cohort of patients identified as having COPD using the algorithm developed in Chapter 2. In this study, quality measures were based on a set of existing quality indicators previously selected through a systematic review and a panel of experts using a Delphi method and consistent with evidence-based practice guidelines.[164] Eleven of the thirty-three QIs were measured using EMR data based on availability of the required data within the structured and semi-structured fields of the EMR database. This chapter describes the limitations found in measuring quality indicators with EMR data in this context. Six of the indicators were applicable to patients with any degree of COPD, while five indicators were intended for those with more advanced stages of COPD or with specific symptoms but assessed for patients with COPD of any severity. These QIs were assessed in EMRALD® to identify the proportion of patients with COPD receiving the indicated care, and these rates were then aggregated to individual physicians' practices to assess proportions of patients with COPD receiving optimal care at the practice level as well as the unadjusted level of variance in practice rates among physicians' rosters. In conclusion, we found that some aspects of COPD care could be measured with EMR routinely collected data.

3. Can EMR data be used to identify provider or patient characteristics that are associated with the provision or receipt of guideline adherent care in chronic disease management?

Chapter 5 sought to identify patient and physician characteristics associated with C-CHANGE cardiovascular guideline adherence measured in Chapter 3. This Chapter demonstrated that EMR data can be linked with external datasets, including administrative claims data and census data to build statistical models that explore patterns of care. This quantitative study assessed patient and physician characteristics to see if they were associated with the odds of C-CHANGE recommendation adherence. Five of the twenty-three quality indicators measured in Chapter 3 were selected for analysis based on lowest adherence and greatest inter-quartile ranges within each of the five measured domains (body habitus, diagnostic testing, risk factor screening, treatment target and pharmacologic/procedural therapy). Women were more likely than men to have their BMI measured, and have their blood pressure under control, and less likely than men to receive antiplatelets for coronary artery disease. We found little difference between patients of different socioeconomic backgrounds after adjusting for clinical and demographic factors. We found that larger roster sizes were associated with less odds of providing antiplatelets to patients who have had stroke and also in testing 2hPG OGTTs. Patients with FPs who were international medical graduates had higher odds of having their blood pressure on target. Patients with physicians who had been practicing longer were also slightly less likely to receive 2hPG OGTT. This study identified substantial unexplained variation in cardiovascular care at the physician- and clinic-level that bring into question their potential impact on health care equitability and accessibility.

Ideally, EMRs would be used to support clinicians in a way that changes suboptimal practice and ensures that all patients receive the ideal care. While EMR tools have the potential to address identified gaps in quality of care, the uptake of EMR tools can be limited in practice. It is important to design and implement tools that will be adopted and used by the end-users. In order to understand the challenges and barriers to the adoption of tools based on EMR data or embedded in the EMRs, our final research question was:

> *4. What are the barriers to, and facilitators for, the adoption of EMR-embedded tools designed to increase guideline-adherence in primary care at the provider and organizational level?*

In Chapter 6, a qualitative study was conducted by interviewing twelve physicians to understand the end-user's perspective of EMR-based quality improvement tools. The tools in this study

included EMR embedded tools and performance audit and feedback reports based on EMR data for improving chronic kidney disease management. The factors concerning adoption and use are not purely technical or clinical, thus this qualitative study used normalization process theory to inform the study design, interview questions and data interpretation through framework analysis. We identified four thematic barriers to adopting quality improvement tools embedded in the EMR and practice performance reports among family physicians. These barriers consisted of misalignment between the tool and physicians' priorities around chronic disease management; technological barriers; organizational barriers; and individual barriers, such as time constraints, work overload and competing priorities. While EMRs can be a tool to improve quality of care, implementation is critical to achieving quality improvement targets. In order to improve implementation and adoption of quality improvement interventions using EMRs, it is important to facilitate adoption by designing and implementing EMR tools in a way that aligns with the physicians' priorities, secures clinician buy-in or clinical champions on-site, limits additional workload and optimizes the level of utility of the tool through design and support.

7.2 Synthesis of main findings

These studies contribute to our understanding of how EMRs can be used to assess primary care practice patterns and improve chronic disease management through EMR-based tools. As previously described, EMRs are large investments in the healthcare system which is projected to grow further in cost. Yet, there is limited evidence on the extent to which EMRs can be used to improve the quality of care received by patients, patient outcomes, or clinical practice. The five studies presented in this thesis demonstrate how EMRs could benefit chronic disease management and quality improvement in Ontario's population. This thesis described possibilities and constraints for the secondary use of EMR data in research as well as the barriers that must be overcome for the future implementation of EMR tools for quality improvement in primary care. The five studies in this thesis contributed to our understanding of secondary use of primary care EMRs in three main ways:

1. They assessed the quality and availability of data and information in primary care EMRs to identify presence of chronic disease in patients and measure quality indicators for chronic disease management.

2. They assessed the potential for EMR data to be used to measure quality of chronic disease care.

3. They identified future considerations for improving uptake of EMRs and EMR based tools to improve quality of care.

Figure **7-1** depicts the various factors that influence the measurability of quality indicators using primary care EMRs. Organizational factors influence clinical practices among physicians, the level of technical advancement in EMR use, and how clinicians use their EMRs daily. These factors, along with the current status of EMR data standards, contribute to the measurability of quality indicators, and influence the value of quality indicator results. As described in Table 7-1 and the sections below, quality indicators must be composed of measurable numerators and denominators which consist of data elements that are accurate, complete and comparable in the EMR. The criteria and case-definition used for the denominator inclusion and exclusion criteria should also be considered in measuring quality indicators as they will impact the relevancy of the results. Both numerator and denominator criteria should be time-specific, and indicators should be relevant to what would be recorded in primary care EMR data. The resulting quality indicators will not only reflect variations in clinical practice, but also variations in EMR recording practice. The measurement of quality indicators can also help identify data gaps in EMRs, future benchmarks, standard rates of care, and quality improvement targets.

7.2.1 Quality and availability of data and information in primary care EMRs to identify presence of chronic disease and measure quality indicators

This thesis sought to assess if the quality and availability of data in primary care EMRs were sufficient to identify presence of chronic disease in patients (specifically, COPD) and identify if patients were receiving recommended care based on clinical guidelines and quality indicators. When EMR data are collected from multiple sites into a database such as EMRALD®, it can be used to reliably identify a population cohort of patients with a specific condition that may otherwise be challenging to identify. The accurate identification of such patients is a critical first step for making an assessment on the quality of care provided to the patient group and for planning targeted quality improvement. When compared with manual chart review and abstraction, EMR data algorithms proved to be highly accurate in identifying patients with COPD. Furthermore, using EMRs to identify presence of disease benefits from relatively low

cost compared to surveys, longitudinal data, reduced recall and self-reporting error and being linked to other clinical information.

It is important to note that algorithms can be and should be adjusted based on their intended use. Case-definitions and algorithms are imperfect, and errors are unavoidable. While our algorithm performed well, it still resulted in a small number of false positive and false negatives. Our discordance analysis found incomplete documentation of diagnosis in the EMR, absence of COPD-specific medications (reflective of incomplete medication lists when patients are getting specialist care), or presence of notes indicating the diagnosis is suspected but unconfirmed. Algorithms should be adjusted for the trade-offs between positive predictive values (PPV) and sensitivity. In our study, the final algorithm resulted in a sensitivity of 77% and PPV of 94%, and the case-definition could be altered to increase the sensitivity to 79%, resulting in a lower PPV of 87%. When compared to previous research, our algorithm fared better in its PPV (with previous published algorithms resulting in PPVs of 80% or less) while maintaining moderate levels of sensitivity similar to findings from other EMR data research. In contrast, administrative claims data in Ontario could be used to identify 85% of patients with COPD but had a PPV of 58%.[59] An optimal balance between these validation statistics should be based on the purpose of the algorithm and whether it is more important to maximize the proportion of true positives (by maximizing PPV) or maximizing the absolute number of true positives by maximizing the sensitivity (at the cost of reduced PPV and introducing a higher number of false positives).

Even with these considerations, the EMR database demonstrated adequate information quality, data quality, accessibility, and relevancy for secondary use of EMR data to identify patients with COPD. EMR data could be used to create a cohort of patients to study at the population level or at individual clinics where clinicians can identify them for quality improvement initiatives. Further, accuracy of EMR-based algorithms can improve in the future with advancements EMR data standards and interoperability for diagnostic tests and other clinical information across the health care spectrum.

In assessing the feasibility of measuring CVD and COPD quality indicators with EMR data, we found that there was sufficient data quality in terms of the accuracy, completeness and availability of the relevant clinical content in the EMR database to assess rates of medication prescription and standardized laboratory tests (such as blood tests). When the data is stored in

comparable structured or semi-structured formats, EMR data can readily be used to measure quality indicators. However, we found that recording practice was variable among physicians. For example, patients' previous medical history were not always complete and should be considered critically when using EMR data for research. This is in line with previous research that found that physicians are not unanimous in deciding what information goes into the problem list.[264] This limitation highlights the importance of appraising the validity of EMR-based measurements and research. The use of EMR data for secondary research and surveillance would be improved with further maturity of EMR adoption so that all relevant clinical information is recorded in the EMR.

There were aspects of care recorded in the EMR that were not readily amenable to analysis as they were embedded in free text, physician- or clinic-specific customized forms/tick boxes, in PDF or picture-like format, or not recorded. Several aspects of care and disease were not well captured as data components in the EMR and omitted from our studies. These omitted components were largely due to limitations in data structure, data standards, practice standards and limited interoperability. They included information on patients' diet and physical exercise; hospitalization information; provision of patient education and counselling. Certain diagnostic tests were not uniformly interpreted and recorded quantitatively. For instance, left ventricular ejection fraction results from echocardiograms or nuclear imaging were not available. Pulmonary function test or spirometry results were inconsistently available, and while digitized to some degree, results were heterogenous in terms of how the results and interpretations were recorded in the EMRs.

Data standards and recording practice are still developing in primary care. The Primary Health Care Information program at CIHI has developed a Pan-Canadian Primary Health Care EMR Content Standard to improve the collection of EMR data elements in a standardized way[265–268]. In respiratory care,[269] ongoing initiatives such as the Pan-Canadian REspiratory STandards INitiative for Electronic Health Records (PRESTINE) may provide solutions to address data concerns around pulmonary function data elements and definitions in EMRs and improve the ability to document and discern severity of disease.[27,269]

7.2.2 Using EMR to measure quality of chronic disease care

As chronic diseases become more prevalent in our aging population, strengthening primary care will become increasingly important. The ability to use existing EMR data to generate information about practice patterns in primary care will be useful for identifying elements of care that warrant attention, from the perspectives of health system surveillance and clinical practice. The studies presented in this thesis (Chapters 3 and 4) demonstrate that it is possible to assess whether patients are receiving some recommended care using primary care EMR data. When the relevant data components are available in the EMR, quality indicators and adherence to clinical guidelines for chronic disease management can be measured in the primary care setting. In the preceding studies, the level of EMR maturity was adequate for assessing multiple aspects of care related to clinical processes and outcomes, including recommended diagnostic testing, risk factor screening and management, and prescription patterns. Aspects of care that could be measured with EMR data using information that was readily obtained through structured data can be particularly useful if the information is not available elsewhere. For example, we found prescription patterns of those who are not covered under the public drug insurance program (covering residents over the age of 65 in Ontario), and thus not present in Ontario administrative databases. Additionally, we found data on immunization rates that can be challenging to obtain elsewhere. It is important to note that several important areas of chronic disease management could not be assessed with EMR data, particularly those surrounding patient lifestyle, diet, nutrition, physical exercise and other components discussed in the limitation section.

The QIs measured in Chapters 3 and 4 reflect real-world practice and indicate that several areas in COPD and CVD management could be improved upon. These measurements can be useful for informing clinicians, researchers and policy makers on suboptimal practice trends identified by gaps between best-evidence and real-world practice. Such results shed light on practices that do not have high-uptake, such as 2-hour plasma oral glucose tolerance tests being administered to patients whose blood tests indicate they are pre-diabetic. The data from EMRs can be further analyzed to identify the presence of gaps in care in the overall population or presence of variation between physicians and clinics. Large variations between practices could indicate that there are potential issues in health care quality such as inequities in access to care, which are both key attributes of health care quality defined by Health Quality Ontario and across Canada.

We found evidence of variation in compliance to clinical guidelines and quality indicators. This indicates that there are gaps in the quality or its evidence in the health care system.[88] We found that a large proportion of the variation found for cardiovascular disease management was due to non-patient factors (related to the physician, clinic or system level that was not necessarily accounted for in our statistical model). We were not able to model all individual factors, physician factors and clinic factors in our models, but other potential sources of variation could include aspects of the patients' life that were not modelled such as diet, nutrition and physical exercise; whether the physician received additional training or material on the recommended care; if they had different caseloads of patients with specific conditions and thus varied levels of exposure and experience; if previous quality improvement initiatives had been implemented at the clinic; or other priorities at the physician or clinic level. The evidence of variation may suggest that to some degree, health care efficiency and effectiveness are not optimal.[89]

7.2.3 Consideration for using EMRs to improve quality of care

The *meaningful use* of EMRs should ideally lead to improvements in the quality of care received by patients and to improvements in patient outcomes. EMRs should be used to identify where there may be deficiencies in the health care system and provide ways to address them if they are unwarranted. One way to address the gaps in care is through the use of EMR tools to improve primary care. Customized tools can help support or modify behaviours around a targeted area of practice. There is a plethora of clinical decision support tools, including reminders, alerts, custom user interface designs for structuring data, risk calculators and access to additional resources. These EMR tools are potentially beneficial for quality improvement initiatives that address any identified gaps between practice and 'optimal' practice to the extent that they are used. However, these tools are only as good as their extent of adoption by the intended users. Our final study demonstrated that in order to develop and implement EMR tools successfully, it is critical to consider multiple social, organizational and technological factors that influence a physician's decision to adopt and use a tool. Implementation of EMR tools requires alignment between the tool's purpose and clinician's priorities, reduced technological barriers, organizational support, clinical leadership and consideration for clinicians' workload.

The growth in EMR use is promising for future research in primary care and future studies can shed more light on how they can be best used to improve chronic disease management. The research described in this thesis has demonstrated that, to a certain degree, data collected from

EMRs allow us to assess the quality of care given in a large population. They can be used to assess whether patients are receiving recommended care and can be used to identify patients in need of additional care. When health care gaps are identified, EMRs can also be used to deliver personalized medicine through advancements in data science and close the gaps so that more individuals can get the medical attention they need.[270,271] While EMR tools can be developed for the purpose of improving patient care, these tools require careful sociotechnical consideration in their design, development and implementation if they are to be adopted by the intended users and achieve the intended and desired impact.

7.3 Strengths, limitations and mitigations

7.3.1 Limitation to the generalizability of study findings

A key limitation of these studies is that it was conducted on a convenience sample of family physicians in Ontario using one type of EMR software. There may be inherent differences between physicians who decide to adopt EMRs and the minority of physicians who are not inclined to do so. Among those who use EMRs, not all physicians use the same EMR software (which determines how the clinically relevant data is structured in the database), nor contribute their data to EMRALD®. At the time of this thesis, it was not possible to get a complete capture of EMR data from all FPs in Ontario. Therefore, the measurements reported in this thesis are approximations of primary care performance and reflect just a portion of the overall health care system and not its overall performance. However, we found that the study population in EMRALD® was similar to the general Ontario population rostered to family physicians, in terms of sex, age distribution and presence of chronic conditions.[99] This study was also conducted in multiple primary care settings and benefited from a large sampling frame of over 300,000 patients from across Ontario, mitigating some of the limitations to generalizability.

Among physicians that do adopt EMRs, there are also varying degrees of adoption and there is evidence of limited use among the adopters. Among EMR adopters, improper use has been observed, and providers' use of EMRs can often be limited to billing and scheduling.[272] Some may use EMRs for electronic documentation, but not for advanced uses for quality improvement or care.[272] The studies in this thesis excluded certain physicians that did not meet certain EMR use criteria, including short duration of use. This may have introduced some bias as the volunteering physicians may already have invested interest in performance and feedback in

addition to the potential bias in addition to the inherent differences between physicians who do or do not adopt EMRs. Some of this bias may be reduced by the fact that physicians may not be volunteering their data as individuals (contributing their data, instead, as part of a larger clinic initiative comprised of multiple physicians.

The findings from this thesis may not be generalizable to the rest of Canada but they can be used as a point of comparison for future studies. Although the scope of the project is limited to one type of EMR in one province, we found that some of the results were consistent with findings from studies with other data sources. The methods and results in this thesis would be relevant in other jurisdictions as EMRs become increasingly standardized and utilized for quality improvement.

7.3.2 Strengths, limitations and mitigations of using primary care EMRs as a secondary data source

There are several advantages to using EMR data. There are limited errors and recall biases of response compared to traditional surveys or questionnaires. Although the preceding studies were cross-sectional in design, the original data is longitudinal, and measurements can be repeated at different time intervals to analyze changes over time. Using systematically collected routine EMR data is advantageous compared to other observational data taken from surveys, which can be cost prohibitive to conduct with larger populations and challenging to reproduce over time. Compared to administrative data, EMRs also has some benefits, namely they contain valuable clinical information unavailable in administrative claims data. This includes, as previously mentioned, medications prescribed to all patients including patients who are under the age of 65 and ineligible for our provincial public drug program. It should be noted that medication prescription rates should be considered a process measure as they do not provide an absolute indication of medication adherence (if patients did not fill the prescription or take the medication as indicated). Conversely, data from administrative claims, community pharmacies or insurance claims have information on prescriptions that were filled and paid for, which would indicate that the patient obtained the medication (although it does not guarantee that they were taken as indicated).

Primary care EMR data provide a snapshot of the clinical practices in the community. Compared to what can be found from audits and research in hospital settings, primary care EMR data

provides an overall picture of the routine care that FPs provided to most of the population. If prevention and management in primary care are important to reduce inpatient and hospitalization, particularly for patients who have chronic diseases, it is important to conduct research in primary care to assess what care is taking place. Information on primary care practice equips us to know what may need to change in order to keep patients healthier, longer in the community and avoid preventable hospitalizations.

There are limitations to EMR data in several aspects related to data quality, availability and analyzability, and how it links to quality of care. It is likely that to some degree, patients' records are incomplete, and there is heterogeneity in recording practices among the physicians that contribute data to the EMR database. When assessing the receipt of guideline recommended care, only the care documented in the EMR would be included in our measurement, which is dependent on the clinicians keeping the EMR up-to-date. Clinics or physicians with insufficient electronic documentation would appear to have lower than the true rates of adherence to the quality indicators. In this regard, what we measure with EMR data is the rate to which physicians record their practice within the EMR data, as an approximate measure of the actual practice. Additionally, the care being studied may have been received by the patient but absent in our analysis. For example, we limited the analysis to structured and semi-structured data, and may have missed relevant information that was stored in unstructured free-text data. Care may have also been received by the patient outside of the primary care clinic, such as medications prescribed by specialists or other physicians not contained in our EMR data, over-the-counter medications, in the hospital, or from community pharmacists, and thus absent from EMR data if not known and recorded by the FP. We know from previous research that there is variation in recording practices even in when there are considerable incentives and explicit mandated directions for how and where to code the information.[40] Some of this variability can be due to distinctiveness of the diagnosis or the potential stigma that may be attached to the disease such as mental health conditions. The presence of variation in data recording practices may be incorrectly captured as clinical practice variation in this study.

To mitigate the limitations of data quality discussed throughout this thesis, we considered EMR data from physicians who have used their EMR within a minimum time frame in the inclusion criteria. This eliminated new users who may be underreporting in their EMRs. The average amount of time that EMRALD® users have used the EMR was over 6 years in the original

studies. When looking at presence of diseases, we used validated algorithms and case-definitions based on previous research. For other components of the EMR such as medication, laboratory findings, diagnostic tests, and consultation letters, we considered the completeness of data capture based on validation against administrative data.[96] We also limited the studies in Chapters 2 to 5 to be based on EMR data components which were likely to have a high degree of completeness and easily amenable to automated analysis, namely data from structured and semi-structured EMR fields. The components of care and quality that were not well captured by EMR data were excluded as outlined in detail in Chapters 3 and 4.

7.3.3 Limitations to the definition and measurement of 'quality' of care

The definition of 'quality' for this thesis was narrow and limited to the aspects of quality as defined by Health Quality Ontario, and by the selected clinically relevant quality indicators for CVD and COPD management. These indicators of quality reflect only a small aspect of healthcare and do not encompass all aspects of healthcare quality. Further research can evaluate and validate whether the measured quality indicators correlate to previously established measures for healthcare process, quality of life or outcome measures (e.g., hospitalization rates, emergency department visits, patient reported experience/outcome measures). There is still a need to establish a directional relationship between the quality indicators and actual quality of care.[87,273–276] The findings from the present research could be used as baseline information for further understanding of the relationship between quality of primary care, namely guideline recommendations and adherence, and health outcomes.

A narrow focus on improving only measured quality indicators risks creating an imbalanced approach to care provision. Several important aspects of high-quality care may not be measurable with EMR data and should not be neglected. Some examples include the physicians' approach or attitude toward the patient during delivery of care, continuity of care, patient education and individualized plans. In addition to some of the quality indicators that could not be measured, there were no indicators on patient experience, wait times, accessibility, integration with other components of the health system, and efficiency. Although equity was assessed to a degree through statistical analyses that included socioeconomic status, other important pillars of primary care quality were not the focus of this research and would require alternative approaches to assessing more comprehensive measures of healthcare quality.

This research was unable to measure the vast majority of clinical guideline recommendations using the described methods due to issues related to the measurability, accessibility and consistency of the data. In order to measure quality indicators using EMR data, both numerator and denominator components must be available and valid in the EMR data. The denominator indicates the eligibility of a patient who should be receiving the care, while the numerator indicates whether or not the patient received the indicated care. If either component is not measurable with EMR data, the quality indicator is not measurable. This research was able to measure less than one-third of the recommendations and quality indicators for CVD and COPD care. In some of the QIs that were measured, there were components of the denominator or numerator that were approximated or altered due to limitations in data availability or validity. These limitations made the quality indicators less specific than they were originally intended. For example, it was not possible to create validated measures of COPD severity using EMR data. Consequentially, quality indicators intended for patients with advanced stages of COPD were measured for all patients with COPD, regardless of the severity. This approach was taken to evaluate the feasibility of measuring the indicator, and to find healthcare utilization rates among all COPD patients as a proxy measure. Although this approach altered the specificity of the original quality indicators, it was able to provide valuable research findings that could be compared with other studies. The limitations in data quality, completeness and availability that were previously noted contributed to the limitations of measuring quality of care with quality indicators in the EMR.

7.3.4 Limitations of generalizability and interpretation of findings from the qualitative study

For the final qualitative study, we interviewed a subset of the study population to gather detailed and nuanced views of the complex issue surrounding EMR tool adoption and use among FPs. However, we interviewed participants beyond data saturation to maximize information gathering and to ensure that no new information was being generated. We employed strategies to maximize participation, including small incentives (gift cards) to recruit as diverse of a participant pool as possible in the available timeline. However, only family physicians were included in our interviews, thus we may be missing perspectives on EMR tool adoption from non-physician actors who are involved with EMR use and implementation, including nurses, technical support staff, quality improvement specialists, and administrative staff.

All qualitative research can introduce the researchers' biases. This was mitigated through interviewing with a second interviewer and having the data and findings reviewed by four independent reviewers. The majority of the interviews were conducted over the phone, limiting the opportunity to see and react to body language and other visible cues. However, due to the limited time available to the participants, benefits of the phone interview (convenience and availability) outweighed the cons.

7.4 Policy implications

7.4.1 Research implications: using EMRs to study primary care

The research presented in this thesis can be used to inform policy aimed at strengthening primary care through the meaningful use of EMRs. Strengthening primary care is crucial to strengthening the healthcare system,[11] as it is the first point of contact for patients, providing a gateway into the larger healthcare system. It provides person-focused care over time, coordinates or integrates care provided elsewhere, and addresses the most common problems in the community by providing preventive, curative and rehabilitative services to maximize health and well-being.[277] As previously mentioned, Canadian primary health care ranks poorly compared to other developed countries and has room to improve.[11,12,16,278]

The studies in this thesis demonstrate that primary care EMR databases like EMRALD® make it possible to identify and study specific population groups based on the presence of a chronic condition and study adherence to clinical recommendations as part of assessing primary care performance. By collecting, analyzing and reporting data on primary care performance, this thesis furthered our understanding of performance measurement in primary care using examples of CVD and COPD in Ontario. It demonstrates that opportunities to improve primary care performance can be identified through the systemic analysis of collected EMR data. Access to performance data and trends is valuable for researchers, care providers and policy makers. By examining current practice patterns and obtaining assessments of family physicians' performance, future researchers have a foundation and baseline with which future comparisons can be made for evaluating interventions and new models of care for chronic disease management. It allows primary care providers to self-evaluate, compare their performance with their peers and implement essential quality improvement initiatives. Policy makers can use the

results from EMR data to be better informed in their health policy decisions regarding primary care.

As EMRs become increasingly used across jurisdictions, it presents many opportunities to study detailed clinical information on larger populations with COPD and CVD.[17,21–23] The studies in this thesis show that primary care EMR data can be a promising source of data to study populations in the community. Using EMR algorithms to identify patients with specific conditions has the potential to help study appropriate use of pharmacological therapy, patient outcomes, health care utilization patterns, and clinical and economic consequences with the ultimate goal of improving patient care and outcomes. Results from studies similar to those presented in this thesis can provide guidance on the areas of chronic disease management warranting attention.[136] To further realize the benefits of EMRs, particularly for studying and improving primary care, future health care policies should support advancements in EMR adoption in primary care, its interoperability with other health information systems, set further EMR data standards and promote EMR-based research.

7.4.2 Clinical implication: chronic disease management and quality improvement

Suboptimal care among a population increases mortality and can be detrimental to the healthcare system as a whole. Health policy plays an important role in shaping healthcare delivery by implementing changes in the design of the healthcare system, or by creating incentives (financial or otherwise) to promote particular care practices that would increase health outcomes of the population. In primary care, it is important to identify which group of patients are not receiving optimal care for chronic disease prevention, treatment and management.

This thesis provided evidence on aspects of CVD and COPD care that have potential for improvement. These findings could help identify targets for quality improvement initiatives and aid in choosing benchmarks for recommended care. Benchmarks are specified standards or points of reference against which quality indicators may be compared to determine whether a predefined level of quality of care was achieved. At the time of this research, there were limited evidence-based benchmarks available in the literature. As such, it may be necessary to replicate the quality indicator measurements within and across jurisdictions to secure meaningful

benchmarks. The use of benchmarks and performance measurement can drive policies toward more targeted improvement in chronic disease management.

When measuring adherence to C-CHANGE recommendations for cardiovascular management, this research found a large degree of variation in the care provided by Ontario family physicians. Although differences in patient characteristics explain most of this observed variation, the multilevel models described in Chapter 5 found that non-patient factors (i.e., physician-, clinic-, or system-level factors) were also substantially responsible. This finding may be reflective of differences among physicians, such as experience and education on the subject matter, or other individual tendencies.

Patient-level factors were most frequently associated with recommendation adherence. In particular, women were more likely than men to have their BMI measured, and have their blood pressure under control, but less likely than men to receive antiplatelet therapy for coronary artery disease. Future investigations are needed to understand if these differences are clinically warranted, or if they are symptomatic of inaccessibility and inequity in the healthcare system. If contraindications for a recommendation were not explicitly stated, guideline bodies could re-evaluate the wording of their published recommendations to improve their levels of specificity for improved measurability within EMRs (e.g., by specifying for whom the recommendation is appropriate, and specifying timeline for its appropriateness). If it is the latter case, health policies must be used as instruments to reduce issues that impinge on health care quality.

This research also found large variation in the management of COPD among family physicians in Ontario. We confirmed previous findings that spirometry rates are low and underutilized in our population, suggesting there should be further investigation to identify the cause of the low rates and potential solutions to improve the spirometry rates. As demonstrated in previous research, patients who have received spirometry have better health outcomes.[195] Additionally, although we found high rates of recording of patients' smoking history, there may be potential to reduce the variation among primary care physicians to provide smoking cessation counselling for more of their patients. We also found suboptimal rates of vaccination and pulmonary rehabilitation in the COPD population. These findings can be taken into account when planning future capacity strengthening or knowledge translation efforts to provide patients with the recommended evidence-based care for CVD and COPD. The results from the studies can help

inform decision-making bodies and policy makers on strategies to improve knowledge translation of guidelines, particularly in areas that have low rates of adherence.

7.4.3 Enhanced use of EMRs

This thesis demonstrates and evaluates the feasibility of using EMRs to inform and improve clinical practice. While billions of dollars have been spent on the development and uptake of EMRs, there is limited, but growing evidence on its benefits, return on investment, and extent of meaningful use at a system level.[15] The studies above attempted to use EMR data to measure primary care practice performance, evaluate patterns of management of CVD and COPD to determine if there is adequate system capacity, quality and uptake of EMRs in primary care to do so. Using EMRs as a tool, there are opportunities to evaluate health services, improve prospective surveillance in public health; measure quality and performance at both system- and individual-levels and improve chronic disease management.[32,33,53,279,280] EMRs could be used to enhance public health surveillance functions, and identify risk factors that improve early detection of disease and changes in health outcomes. This area of research can influence the quality of health care and clinical practice that improves morbidity and quality of life. Findings from this thesis that are relevant to meaningful use of EMRs can inform policies to shape the future of information science in health care.

The findings from this thesis indicate that there are heterogeneities and limitations how physicians record clinical encounter and use EMRs as well as EMR tools. We identified that in some cases, there were limited up-to-date records of the cumulative patient profile, problem list and diagnostic tests. This was in line with one of our findings from Chapter 6 which highlight the heavy workload of FPs and their time constraints. The findings also suggest that the health information gap could be addressed by increased support to end-users who are using EMRs. In this regard, the roles of data clerks, health informaticians, quality improvement specialists or nurses could be explored from a policy perspective in order to fully realize the value of EMRs. In order for EMR tools to be adopted by clinicians, there needs to be perceived alignment between their priorities and their perceived purpose of the tools. Future policies can help guide developers of EMR tools to consider their stakeholders' and end-users' priorities more fully.

Addressing barriers to adopting EMRs and EMR tools would further enhance the use of EMRs in primary care. Policies can encourage reduction of technological and organizational barriers to

adoption of advanced EMR use. Policies can help support this by recommendations that include additional availability of support staff in updating EMRs; improved interoperability of health information between service providers; improved user experience that make more advanced features of EMRs more intuitive; or less time-consuming for users while maintaining accuracy and data standards.

7.5 Future research directions

The research conducted in this thesis found that EMR data can be used to study quality of care, which is particularly important for understudied populations such as patients with COPD. We identified several important aspects to consider when measuring quality indicators in primary care EMRs. However, additional research is required to fully understand the current limitations of EMR data and its data quality. The work presented in this thesis should be supplemented with research focused on ways to improve EMR data without negatively impacting user experience or clinical practice. It is still unknown how effectively EMR data and quality improvement tools could most effectively modify user behaviour and clinical practice to improve primary care quality.

Below, three potential future research areas are highlighted, namely studying how to use EMRs at the point of care to improve quality of care; comparing our findings with other data sources; and using different methods to study primary care quality with EMR data.

7.5.1 Using EMRs at the point of care to improve quality of care

Suboptimal levels of process-based quality indicators were found for several aspects of the care studied in this thesis. These included the rates of vaccination and spirometry in our COPD population, and risk factor screening by asking about smoking history in the general population, providing and supporting smoking cessation to current smokers, and large degrees of variation in clinical practice indicating suboptimal health care quality at the system level. Interventions can be designed, developed, implemented and studied to find the most effective way of improving care and improving adherence to the quality indicators. Interventions can include built-in tools in the EMRs to be used at the point of care; interventions to support performance self-audit and feedback; or other knowledge translation interventions such as paper-based educational material or training programs.

Future projects on EMR tools should focus on reducing the barriers to implementation success identified in this thesis. Any EMR-based quality improvement intervention or clinical decision support tool should be tested for their usability, potential for clinical uptake, impact on clinical practice and impact on patient outcomes so as to work with the existing workflow and reduce time lost for the user. The design and development of EMR tools should align with physicians' priorities, be intuitive to use and improve the clinic workflow. This can be done by conducting research in multiple phases that include the end-users and stakeholders at all steps, such as requirements gathering, user experience testing, pilot testing, and incorporate multiple rounds of design and development so as to maximize the probability that the tool would be used at the point of care. If a pilot test is successful, only then should it be rolled out to a larger trial where the effectiveness of the tool could be evaluated. A multi-pronged study design can methodologically compare different types of EMR tools to assess its relative impact on quality improvement and modifying behaviours.

7.5.2 Comparison of results with other data sources

The studies in this thesis were limited to data derived from family physicians that used Telus Practice Solutions Suite EMR in the province of Ontario. To further our understanding of primary care practice patterns in Ontario, future research should be directed toward investigating which other EMRs may be used as data sources for research and developing ways to analyze information from other EMR sources (including OSCAR EMR, Accuro EMR). Our findings can also be compared with external data sources, such as administrative data or survey data from within the province or outside of Ontario.

While Practice Solutions Suite EMR was noted to be the most widely used primary care EMR in Ontario, there are a myriad of other EMRs that are used by other FPs.[165] Future research efforts to include and compare our results with data from other sources will allow a more comprehensive picture of the health care system, validate our findings, and also understand the benefits, limitations and differences between currently available EMR systems. This future research could be made possible with research initiatives like the University of Toronto Practice-Based Research Network (UTOPIAN)[281] which would harness data from multiple EMR vendor software. Conducting the research in this thesis with other EMR data sources would allow us to compare results and further understand if some of the variation is due to variation in database structures and data capture in the particular EMR software, or variation in clinical practice

patterns. It would be important to understand the information architecture and data structures among all the available EMRs in Ontario to realize the benefits of health information systems and enable region-wide evaluation of EMR use and health care planning.

Some of our results can also be validated with research based on administrative claims data to see the degree to which the rates of quality indicators are similar. This would be possible to do for rates of medication prescribed to patients who are insured (patients over the age of 65 who have public drug insurance coverage). This comparison would help validate our findings if the rates are similar among the insured group, and also provide information on specialist versus primary care, and possible issues surrounding medication adherence and compliance if the rates were vastly different. For example, if prescription rates were higher in the EMR than in the administrative and insurance claims data, that would mean patients were receiving prescriptions from their FPs but not filling them in at the pharmacy. Conversely if the prescription rates were lower in the EMR than the administrative database, that would indicate that FPs EMRs are not up-to-date or that specialists' prescribing details were not made available or recorded in the FPs' office. Similarly, administering surveys at clinics or performing a chart audit of a certain subset of the clinics in our study would strengthen the validity of our findings. Use of other datasets and additional chart audits may also be required in order to develop additional validated EMR algorithms, such as classification of COPD severity that we did not include in our studies, and also enable the measurement of other quality indicators.

Future comparisons of results can be made not only with other data sources within in Ontario but also with other jurisdictions in Canada and abroad. Research with data from other regions and other data sources would enable greater understanding of health care service trends and foresee the needs of providing quality care for chronic disease management. This in turn can help identify meaningful benchmarks and inform changes in policies to strengthen the health care system, particularly primary care.

7.5.3 Improvements in analysis and health information systems

Two-thirds of the original quality indicators and recommendations in the harmonized guidelines were not measured in our studies. There may be interest in future research to develop ways to measure these components of care to obtain a more comprehensive view of the quality of chronic disease management in primary care. The indicators that were not measured in this thesis were

particularly around aspects of care that are not documented in EMRs in a way that it was amenable for data analysis. Some of the limitations were due to limited interoperability between primary care EMR data, hospital data, and limited standardization of certain diagnostic tests such as spirometry or echocardiograms. Future research is warranted to find optimal ways of standardizing and operationalizing information flow between health providers in order to achieve a comprehensive clinical dataset that enables us to understand and study our health care system as a whole. This wound enable the monitoring of the heatlh care system and identify ways to improve delivery of care not only at the point of care, but also by improvements in the information infrastructure where health information is exchanged.

Part of the limitations to non-measurement was due to the methods used in analysis. More advanced computing techniques that involve data mining and natural language processing offer future potential to identify patterns of care with unstructured data elements in the EMR that were not considered in this thesis. Future research using these advanced techniques could potentially find useful information about other important aspects of chronic disease management in the EMR, such as patients' lifestyle, diet, and physical exercise.

Future integration with databases and external data sources will also expand the scope of research that is possible. As the population gets older and there are increased prevalence of chronic disease, there may be a more prominent focus on improving self-management and prevention throughout patients' life course. With the advent of telehealth monitoring technologies and ubiquitous mobile health applications, there may be an increase in data linkages between clinicians' offices, data integration with homecare and self-care information. Because there may be linkages with primary care EMR data as well, there may be opportunities to research how these additional data sources play a role in assessing the patients' health and health care needs. These platforms may also provide new ways to improve and assess some of the quality indicators, such as those surrounding routine monitoring, patient lifestyles (smoking habits, nutrition and physical exercise) or patient education. Integrating other aspects of healthcare that are not delivered at a health facility or the family physicians' offices may provide an opportunity for future research to study chronic disease management and patient care in a more holistic and comprehensive way.

7.6 Conclusion

The goal of this thesis was to find out if primary care EMRs could be used to study, assess and improve the quality of chronic disease management. Through five original studies, this thesis explored a number of ways in which primary care EMRs could be used meaningfully to target improvements in chronic disease management. Identifying patients with certain conditions accurately is essential to being able to target quality improvement initiatives and conduct an audit of current performance. The thesis demonstrated that EMRs could be used to accurately identify patients with complex conditions such as COPD. This thesis further demonstrated that data from primary care EMRs could be harnessed to measure the rate at which patients with certain conditions are receiving recommended care. In two studies, we demonstrated that aspects of chronic disease care, namely primary care physicians' adherence to clinical practice guidelines and quality indicators for cardiovascular disease and COPD are possible to measure readily if they are quantifiable or coded in semi-structured or structured formats in the EMR. For aspects of care that had low adherence rates or high level of variance in practice, we linked the findings to external data sources to investigate if there are provider or patient characteristics that are associated with meeting the quality indicator criteria. We provided an example of how health service utilization data, socioeconomic data and clinical data from EMRs could be combined to investigate epidemiological research questions. Finally, we identified barriers to the adoption and routine use of EMR-embedded tools and audit and feedback tools designed to increase guideline-adherence in primary care through thematic analysis. This research provided insight into important considerations for building a quality improvement intervention using EMR data as a platform or data source.

Adoption and use of EMRs are still growing and continuing to change in the primary care delivery landscape. We identified key limitations to using EMR data to measure primary care quality, as well as a conceptual model that describes factors that impact measurability of quality indicators within primary care EMRs. These findings would be important to consider in future efforts to use EMRs for primary care quality improvement and performance management. There is still much to understand about maximizing the benefits of EMRs in primary care. This thesis provided proof of concept that primary care EMRs could be used to identify patients with a certain condition, and assess clinical quality measures with process and outcome indicators measurable in the EMR. However there are many limitations still with EMR data quality, EMR

data standards, clinical variation in practice and EMR use. It is essential that policymakers take into consideration sociotechnical aspects of the healthcare system and delivery when considering the use of EMRs for quality improvement.

7.7 Tables and figures

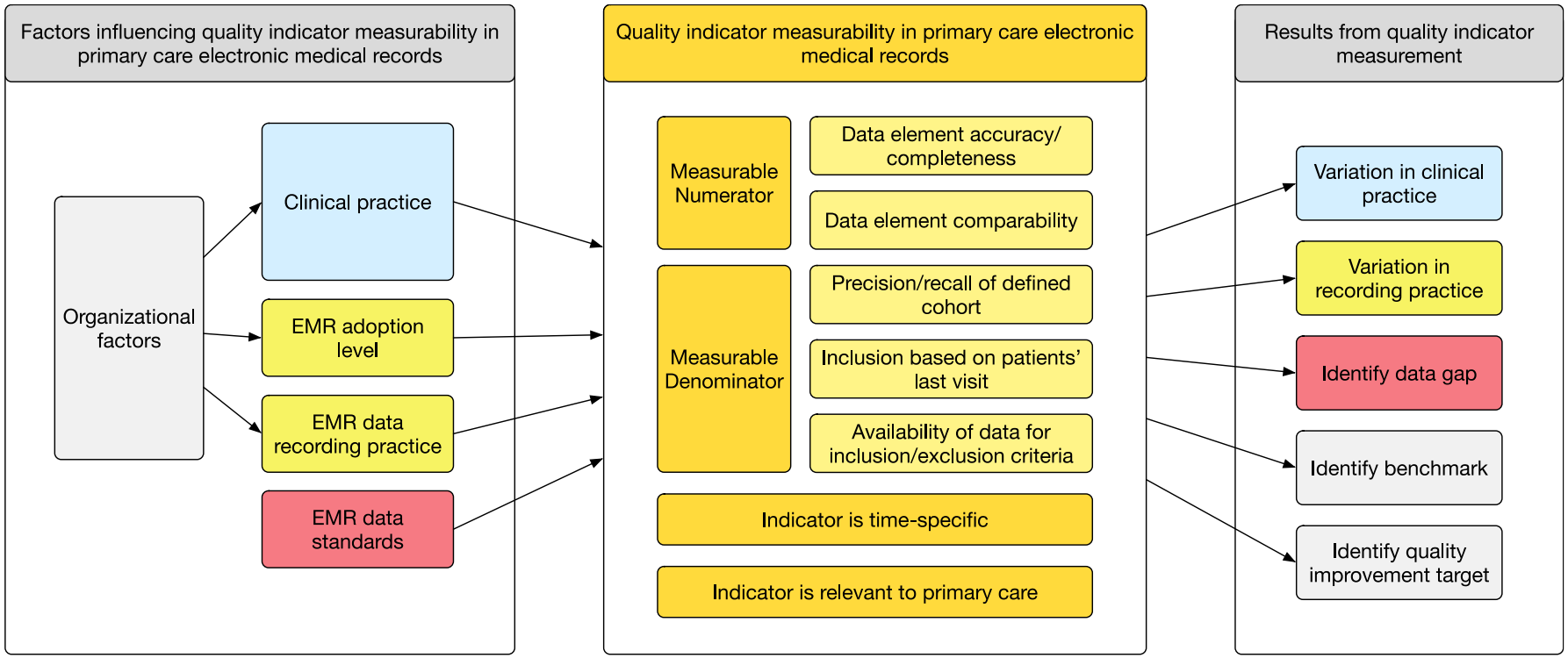


Figure 7-1 Quality indicator measurability in primary care electronic medical records, factors influencing quality indicator measurability and results from measurement

Table 7-1 Factors contributing to measurability of quality indicators in primary care electronic medical records

Quality indicator element	Measurability factors	Example	Potential impact on results
Numerator			
	Data element accuracy and completeness: The care indicated for the patient should be recorded in the EMR when it has taken place	Some physicians may measure patients' weight but not record it in the EMR Urinalysis may be done at the clinic and the results may not be recorded in the EMR	Incompleteness will increase variability, and when it does not reflect the reality of practice, will skew the indicator results (in most cases, to be lower than actual practice)
	Data element comparability: The care indicated should be recorded in standardized format and consistent for all users and over time	Nomenclature for spirometry results are not standardized and sometimes numeric in different data formats (percentages or decimals or text strings)	Indicator will not be comparable. It would be possible to see approximate indication of the process measure taking place for the example of spirometry, but difficult to assess if results of spirometry were concordant with the diagnosis of a respiratory condition
Denominator			
	Precision/recall of defined cohort: Case-definition of relevant population should be validated	Accuracy and recall of algorithm or case-definition may be limited and exclude a large number of relevant patients; or include too many individuals for whom the indicator is not relevant	The results may be skewed based on the precision and recall values of case-definition used for defining relevant population
	Inclusion of patients based on last visit: Timeframe for last clinical encounter with physician should be appropriate	Cohort should indicate the timeframe in which the patient has had an encounter with the physician (e.g. patient has a claim recorded in the last 24 months)	The number of patients who have not had a clinical encounter (lost to follow-up) who remain in the denominator will lower the results
	Availability of data for inclusion/exclusion criteria: Certain criteria	Criteria such as patient ethnicity or family history are often not	Aspect of the indicator is not measurable and

Quality indicator element	Measurability factors	Example	Potential impact on results
	may not be available in EMR data	well recorded in standard format in the EMR	results may be less relevant
Time-specific	Indicator is time-specific: The time frame in which the action should be performed, or the outcome is valid should be defined	Process indicator example: the proportion of patients with diabetes who have a HbA1c test recorded in the *last 18 months;* outcome indicator example: proportion of patients with diabetes whose last fasting plasma glucose test result *in the last 12 months* was on target.	Indicator should be time-specific and relevant. A shorter timeframe may lower results, and no time restrictions may increase the results.
Relevance	Indicator is relevant to primary care: The element of care should be appropriate to search in primary care electronic medical records	Hospitalization records are currently not well captured in primary care EMRs; patient may be under care of specialists to receive the indicated care	Indicator should be relevant to the database being queried; if care is received elsewhere but is not recorded, it may lower the results and increase variability

References

1. Canada Health Infoway. Investment Programs - Canada Health Infoway. (2015). Available at: https://www.infoway-inforoute.ca/en/what-we-do/progress-in-canada/investment-programs. (Accessed: 28th January 2016)
2. OntarioMD. EMR Funding Overview. (2016). Available at: www.ontariomd.ca/portal/server.pt/community/emr_funding/new_emr_adopters. (Accessed: 20th June 2016)
3. Physician Information Technology Office (PITO). *EMR Adoption Study*. (2013).
4. Rimmer, C., Hagens, S., Baldwin, A. & Anderson, C. J. Measuring Maturity of Use for Electronic Medical Records (EMRs) in British Columbia: The Physician Information Technology Office (PITO). *Healthc. Q.* **17**, 75–80 (2014).
5. Canada Health Infoway. 2018 Canadian Physician Survey Physicians' Use of Digital Health and Information Technologies in Practice Background and Methodology. 1–31 (2018).
6. Canada Health Infoway. *2015: Advancing Canada's Next Generation of Healthcare*. (2015).
7. Canadian Medical Association. How can Canada achieve enhanced use of electronic medical records? (2014).
8. Zucker, L. & Canada Health Infoway. Clinical Value: 'Meaningful Use' in Canada. (2011). Available at: http://infowayconnects.infoway-inforoute.ca/2011/02/16/clinical-value-meaningful-use-in-canada/. (Accessed: 7th February 2016)
9. Terry, A. L. *et al.* Implementing electronic health records: Key factors in primary care. *Can. Fam. Physician* **54**, 730–736 (2008).
10. 111th Congress. HITECH ACT 2009: TITLE XIII OF the American Recovery and Reinvestment Act 2009 111th. *U.S. Government Printing Office Public Law 111–5* 1–407 pg. 112 (2009).
11. Health Quality Ontario. *A Primary Care Performance Measurement Framework: Report of the Steering Committee for the Ontario Primary Care Performance Measurement Initiative Phase One.* (2014).
12. Schoen, C. *et al.* A Survey Of Primary Care Doctors In Ten Countries Shows Progress In Use Of Health Information Technology, Less In Other Areas. *Health Aff.* **31**, 2805–2816 (2012).
13. Canadian Institute for Health Information (CIHI). *How Canada Compares: Results From The Commonwealth Fund 2015 International Health Policy Survey of Primary Care Physicians*. (2016).
14. Katz, A., Glazier, R. H. & Vijayaraghavan, J. *The health and economic consequences of achieving a high-quality primary healthcare system in Canada 'Applying what works in Canada: closing the gap'*. (2009).
15. Lau, F., Price, M. & Bassi, J. Toward a Coordinated Electronic Health Record (EHR) Strategy for Canada. in *Toward a Healthcare Strategy for Canadians* (eds. Carson, A. S., Dixon, J. & Nossal, K. R.) 111–134 (McGill-Queen's University Press, 2015).

16. Hutchison, B. Reforming Canadian primary care - Don't stop half-way. *Healthc. Policy* **9**, 12–25 (2013).

17. Public Health Agency of Canada. Tracking Heart Disease and Stroke in Canada. 1–5 (2011).

18. Global Initiative for Chronic Obstructive Lung Disease. *Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease (Revised 2011)*. *Marketing Management* (2011).

19. World Health Organization. Chronic obstructive pulmonary disease (COPD). Available at: http://www.who.int/respiratory/copd/en/. (Accessed: 1st June 2015)

20. Lozano, R. *et al.* Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* **380**, 2095–2128 (2012).

21. Buist, A. S. *et al.* International variation in the prevalence of COPD (The BOLD Study): a population-based prevalence study. *Lancet* **370**, 741–750 (2007).

22. Halbert, R. *et al.* Global burden of COPD: systematic review and meta-analysis. *Eur Respir J* **28**, 523–532 (2006).

23. Chapman, K. R. *et al.* Epidemiology and costs of chronic obstructive pulmonary disease. *Eur. Respir. J. Off. J. Eur. Soc. Clin. Respir. Physiol.* **27**, 188–207 (2006).

24. Faulconer, E. & DeLusignan, S. An eight-step method for assessing diagnostic data quality in practice: chronic obstructive pulmonary disease as an exemplar. *J. Innov. Heal. Informatics* **12**, 243–253 (2004).

25. Green, C. J., Fortin, P., Maclure, M., Macgregor, A. & Robinson, S. Information system support as a critical success factor for chronic disease management: Necessary but not sufficient. *Int. J. Med. Inform.* **75**, 818–828 (2006).

26. Choi, P. P., Day, A. & Etchells, E. Gaps in the care of patients admitted to hospital with an exacerbation of chronic obstructive pulmonary disease. *CMAJ* **170**, 1409–1413 (2004).

27. Lougheed, M. D. *et al.* Pan-Canadian REspiratory STandards INitiative for Electronic Health Records (PRESTINE): 2011 national forum proceedings. *Canadian respiratory journal : journal of the Canadian Thoracic Society* **19**, 117–126 (2012).

28. Hernandez, P. *et al.* Canadian practice assessment in chronic obstructive pulmonary disease: Respiratory specialist physician perception versus patient reality. *Can. Respir. J.* **20**, 97–105 (2013).

29. Lindenauer, P. K. *et al.* Quality of care for patients hospitalized for acute exacerbations of chronic obstructive pulmonary disease. *Ann. Intern. Med.* **144**, 894–903 (2006).

30. Mularski, R. A. *et al.* The quality of obstructive lung disease care for adults in the United States as measured by adherence to recommended processes. *Chest* **130**, 1844–1850 (2006).

31. Sandhu, S. K. *et al.* Variations in the Management of Acute Exacerbations of Chronic Obstructive Pulmonary Disease. *Can. Respir. J.* **20**, 175–179 (2013).

32. Agarwal, R., Gao, G. (Gordon), DesRoches, C. & Jha, A. K. Research Commentary — The Digital Transformation of Healthcare: Current Status and the Road Ahead. *Inf. Syst.*

Res. **21**, 796–809 (2010).

33. Brown, J. S. *et al.* Early detection of adverse drug events within population-based health networks: application of sequential testing methods. *Pharmacoepidemiol. Drug Saf.* **16**, 1275–1284 (2007).

34. Yusof, M. M., Papazafeiropoulou, A., Paul, R. J. & Stergioulas, L. K. Investigating evaluation frameworks for health information systems. *Int. J. Med. Inform.* **77**, 377–85 (2008).

35. Mabotuwana, T., Warren, J. & Kennelly, J. A computational framework to identify patients with poor adherence to blood pressure lowering medication. *Int. J. Med. Inform.* **78**, 745–756 (2009).

36. Comer, K. F., Grannis, S., Dixon, B. E., Bodenhamer, D. J. & Wiehe, S. E. Incorporating Geospatial Capacity within Clinical Data Systems to Address Social Determinants of Health. *Public Health Rep.* (2011).

37. Kukafka, R. *et al.* Redesigning electronic health record systems to support public health. *J. Biomed. Inform.* (2007). doi:10.1016/j.jbi.2007.07.001

38. Tu, K., Mitiku, T., Lee, D. S., Guo, H. & Tu, J. V. Validation of physician billing and hospitalization data to identify patients with ischemic heart disease using data from the Electronic Medical Record Administrative data Linked Database (EMRALD). *Can. J. Cardiol.* **26**, e225-8 (2010).

39. Kadhim-Saleh, A., Green, M., Williamson, T., Hunter, D. & Birtwhistle, R. Validation of the diagnostic algorithms for 5 chronic conditions in the Canadian Primary Care Sentinel Surveillance Network (CPCSSN): a Kingston Practice-based Research Network (PBRN) report. *J. Am. Board Fam. Med.* **26**, 159–167 (2013).

40. Herrett, E. *et al.* Completeness and diagnostic validity of recording acute myocardial infarction events in primary care, hospital care, disease registry, and national mortality records: cohort study. *BMJ* **346**, f2350 (2013).

41. Khader, A. *et al.* Cohort monitoring of persons with diabetes mellitus in a primary healthcare clinic for Palestine refugees in Jordan. *Trop. Med. Int. Health* **17**, 1569–1576 (2012).

42. Peiris, D. *et al.* Cardiovascular risk management at a Maori-led Primary Health Organisation--findings from a cross-sectional audit. *N. Z. Med. J.* **121**, 35–46 (2008).

43. Vila-Corcoles, A. *et al.* Clinical effectiveness of pneumococcal vaccination against acute myocardial infarction and stroke in people over 60 years: the CAPAMIS study, one-year follow-up. *BMC Public Health* **12**, 222 (2012).

44. Vogel, T. R., Su, L. T., Symons, R. G. & Flum, D. R. Lower extremity angioplasty for claudication: a population-level analysis of 30-day outcomes. *J. Vasc. Surg.* **45**, 762–767 (2007).

45. Crawford, A. G. *et al.* Prevalence of obesity, type II diabetes mellitus, hyperlipidemia, and hypertension in the United States: findings from the GE Centricity Electronic Medical Record database. *Popul. Health Manag.* **13**, 151–161 (2010).

46. Piazza, G. & Goldhaber, S. Z. Improving clinical effectiveness in thromboprophylaxis for hospitalized medical patients. *Am. J. Med.* **122**, 230–232 (2009).

47. Salem, R. M. *et al.* The VA Hypertension Primary Care Longitudinal Cohort: Electronic medical records in the post-genomic era. *Health Informatics J.* **16**, 274–286 (2010).

48. Flynn, R. W. V, MacDonald, T. M., Murray, G. D., MacWalter, R. S. & Doney, A. S. F. Persistence, adherence and outcomes with antiplatelet regimens following cerebral infarction in the Tayside Stroke Cohort. *Cerebrovasc. Dis.* **33**, 190–197 (2012).

49. Warren, J. *et al.* Prescribing history to identify candidates for chronic condition medication adherence promotion. *Stud. Health Technol. Inform.* **169**, 634–638 (2011).

50. Ornstein, S. M. & Jenkins, R. G. Quality of care for chronic illness in primary care: opportunity for improvement in process and outcome measures. *Am. J. Manag. Care* **5**, 621–627 (1999).

51. Ornstein, S. M. Translating research into practice using electronic medical records the PPRNet-TRIP project: primary and secondary prevention of coronary heart disease and stroke. *Top. Health Inf. Manage.* **22**, 52–58 (2001).

52. Gillies, A. & Rawlings, G. Can computers improve the Health of the Nation? *Stud. Health Technol. Inform.* **43 Pt B**, 889–893 (1997).

53. Mabotuwana, T. & Warren, J. ChronoMedIt--a computational quality audit framework for better management of patients with chronic conditions. *J. Biomed. Inform.* **43**, 144–158 (2010).

54. Cragg, J. J., Warner, F. M., Kramer, J. K. & Borisoff, J. F. A Canada-wide survey of chronic respiratory disease and spinal cord injury. *Am. Acad. Neurol.* 1341–1345 (2015).

55. Radeos, M. S. *et al.* Validation of self-reported chronic obstructive pulmonary disease among patients in the ED. *Am. J. Emerg. Med.* **27**, 191–196 (2009).

56. Barr, R. G., Herbstman, J., Speizer, F. E. & Camargo Jr., C. A. Validation of self-reported chronic obstructive pulmonary disease in a cohort study of nurses. *Am J Epidemiol* **155**, 965–971 (2002).

57. Bergna, M. A. *et al.* Development of a simple binary response questionnaire to identify airflow obstruction in a smoking population in Argentina. *Eur. Respir. Rev.* **24**, 320–326 (2015).

58. Cooke, C. R. *et al.* The validity of using ICD-9 codes and pharmacy records to identify patients with chronic obstructive pulmonary disease. *BMC Health Serv. Res.* **11**, 37 (2011).

59. Gershon, A. S. *et al.* Identifying individuals with physcian diagnosed COPD in health administrative databases. *COPD* **6**, 388–394 (2009).

60. Lacasse, Y., Daigle, J.-M., Martin, S. & Maltais, F. Validity of chronic obstructive pulmonary disease diagnoses in a large administrative database. *Can Respir J* **19**, 207–214 (2012).

61. Mapel, D. W. *et al.* The direct medical costs of undiagnosed chronic obstructive pulmonary disease. *Value Heal.* **11**, 628–636 (2008).

62. Smidth, M., Sokolowski, I., Kærsvang, L. & Vedsted, P. Developing an algorithm to identify people with Chronic Obstructive Pulmonary Disease (COPD) using administrative data. *BMC Med. Inform. Decis. Mak.* **12**, 1–7 (2012).

63. Dean, B. B. *et al.* Use of electronic medical records for health outcomes research. *Med. Care Res. Rev.* **66**, 611–638 (2009).

64. Greiver, M. *et al.* Prevalence and epidemiology of diabetes in Canadian primary care practices: a report from the Canadian Primary Care Sentinel Surveillance Network. *Can. J. diabetes* **38**, 179–185 (2014).

65. Coleman, N. *et al.* From patient care to research: a validation study examining the factors contributing to data quality in a primary care electronic medical record database. *BMC Fam. Pract.* **16**, 11 (2015).

66. Quint, J. K. *et al.* Validation of Chronic Obstructive Pulmonary Disease Recording in the Clinical Practice Research Datalink (CPRD-GOLD). *BMJ Open* **4**, e005540–e005540 (2014).

67. Soriano, J. B., Maier, W. C., Visick, G. & Pride, N. B. Validation of general practitioner-diagnosed COPD in the UK General Practice Research Database. *Eur. J. Epidemiol.* **17**, 1075–1080 (2001).

68. Ward, K. & Hubbard, R. Is adult height related to the risk of having chronic obstructive pulmonary disease? *J. Epidemiol. Community Health* **65**, 226–229 (2011).

69. Mullerova, H., Shukla, A., Hawkins, A. & Quint, J. Risk factors for acute exacerbations of COPD in a primary care population: a retrospective observational cohort study. *BMJ Open* **4**, e006171 (2014).

70. Vasankari, T., Pietinalho, A., Lertola, K., Junnila, S. Y. & Liippo, K. Use of spirometry and recording of smoking habits of COPD patients increased in primary health care during national COPD programme. *BMC Fam. Pract.* **12**, 97 (2011).

71. Jara, M., Lanes, S. F., Wentworth, C. 3rd, May, C. & Kesten, S. Comparative safety of long-acting inhaled bronchodilators: a cohort study using the UK THIN primary care database. *Drug Saf.* **30**, 1151–1160 (2007).

72. Gill, J. M., Klinkman, M. S. & Chen, Y. X. Antidepressant medication use for primary care patients with and without medical comorbidities: a national electronic health record (EHR) network study. *J. Am. Board Fam. Med.* **23**, 499–508 (2010).

73. Sonstein, L., Clark, C., Seidensticker, S., Zeng, L. & Sharma, G. Improving adherence for management of acute exacerbation of chronic obstructive pulmonary disease. *Am. J. Med.* **127**, 1097–1104 (2014).

74. Bates, D. W. Effect of Computerized Physician Order Entry and a Team Intervention on Prevention of Serious Medication Errors. *JAMA* **280**, 1311 (1998).

75. Persell, S. D., Lloyd-Jones, D. M., Friesema, E. M., Cooper, A. J. & Baker, D. W. Electronic health record-based patient identification and individualized mailed outreach for primary cardiovascular disease prevention: a cluster randomized trial. *J. Gen. Intern. Med.* **28**, 554–560 (2013).

76. Varroud-Vial, M. Improving diabetes management with electronic medical records. *Diabetes Metab.* **37**, S48–S52 (2011).

77. Kinn, J. W., Marek, J. C., O'Toole, M. F., Rowley, S. M. & Bufalino, V. J. Effectiveness of the electronic medical record in improving the management of hypentension. *J. Clin. Hypertens.* **4**, 415–419 (2002).

78. Haj-ali, W. & Tchison, B. H. Establishing a Primary Care Performance Measurement Framework for Ontario Mise en place d'un cadre pour la mesure du rendement des soins primaires en Ontario Establishing a Primary Care Performance Measurement Framework for Ontario. *Healthc. Policy* **661212**, 66–79 (2017).

79. May, C. & Finch, T. Implementing, Embedding, and Integrating Practices: An Outline of Normalization Process Theory. *Sociology* **43**, 535–554 (2009).

80. Health Quality Ontario. Ontario Primary Care Performance Measurement Initiative: Phase One. (2012).

81. *Excellent Care for All Act*. (2010).

82. Institute of Medicine. Crossing the quality chasm: a new health system for the 21th century. 1–8 (2001).

83. Hayward, R., Wilson, M., Tunis, S., Bass, E. & Guyatt, G. Users' Guide to the Medical Literature VIII. How to Use Clinical Practice Guidelines. *JAMA J. Am. Med. Assoc.* **274**, 570–574 (1995).

84. Garber, A. M. Evidence-based guidelines as a foundation for performance incentives. *Health Aff.* **24**, 174–179 (2005).

85. Sackett, D. L., Rosenberg, W. M. C., Gray, J. A. M., Haynes, R. B. & Richardson, W. S. Evidence based medicine: what it is and what it isn't. *BMJ* **312**, 71–72 (1996).

86. Woolf, S. H., Grol, R., Hutchinson, A., Eccles, M. & Grimshaw, J. Clinical guidelines: Potential benefits, limitations, and harms of clinical guidelines. *BMJ* **318**, 527–530 (1999).

87. Lugtenberg, M., Burgers, J. S. & Westert, G. P. Effects of evidence-based clinical practice guidelines on quality of care: a systematic review. *Qual. Saf. Health Care* **18**, 385–392 (2009).

88. Agency for Healthcare Research and Quality. Improving Health Care Quality. 1–6 (2002).

89. Wennberg, J. E. Time to tackle unwarranted variations in practice. *BMJ* **342**, d1513 (2011).

90. Novak, L. L., Holden, R. J., Anders, S. H., Hong, J. Y. & Karsh, B.-T. Using a sociotechnical framework to understand adaptations in health IT implementation. *Int. J. Med. Inform.* **82**, e331-44 (2013).

91. Kennedy, A. *et al.* Implementation of a self-management support approach (WISE) across a health system : a process evaluation explaining what did and did not work for organisations , clinicians and patients. 1–16 (2014). doi:10.1186/s13012-014-0129-5

92. May, C. Mobilising modern facts: Health technology assessment and the politics of evidence. *Sociology of Health and Illness* **28**, 513–532 (2006).

93. May, C., Mort, M., Williams, T., Mair, F. & Gask, L. Health technology assessment in its local contexts: Studies of telehealthcare. *Soc. Sci. Med.* **57**, 697–710 (2003).

94. Bouamrane, M.-M. & Mair, F. S. A study of general practitioners' perspectives on electronic medical records systems in NHSScotland. *Med. Informatics Decis. Mak.* **13**, (2013).

95. Bouamrane, M.-M. & Mair, F. Integrated Preoperative Care Pathway - A Study of a

Regional Electronic Implementation. *BMC Med. Informatics Decis. Mak.* **14**, 1–32 (2014).

96. Tu, K. *et al.* Evaluation of Electronic Medical Record Administrative data Linked Database (EMRALD). *Am. J. Manag. Care* **20**, 15–21 (2014).

97. Schwartz, K. L. *et al.* Comparing prescribing and dispensing databases to study antibiotic use: a validation study of the Electronic Medical Record Administrative data Linked Database (EMRALD). *J. Antimicrob. Chemother.* **74**, 2091–2097 (2019).

98. Tu, K. *et al.* Are family physicians comprehensively using electronic medical records such that the data can be used for secondary purposes? A Canadian perspective. *BMC Med. Informatics Decis. Mak.* **15**, 67 (2015).

99. Tu, K. *et al.* Are family physicians comprehensively using electronic medical records such that the data can be used for secondary purposes? A Canadian perspective. *BMC Med. Informatics Decis. Mak.* **15**, 67 (2015).

100. Hill, K. *et al.* Prevalence and underdiagnosis of chronic obstructive pulmonary disease among patients at risk in primary care. *CMAJ* **182**, 673–678 (2010).

101. Ställberg, B. *et al.* Management, morbidity and mortality of COPD during an 11-year period: An observational retrospective epidemiological register study in Sweden (PATHOS). *Prim. Care Respir. J.* **23**, 38–45 (2014).

102. Williamson, T. *et al.* Validating the 8 CPCSSN Case Definitions for Chronic Disease Surveillance in a Primary Care Database of Electronic Health Records. *Ann. Fam. Med.* **12**, 367–372 (2014).

103. van Boven, J. F. M. *et al.* Predictors of cost-effectiveness of selected COPD treatments in primary care: UNLOCK study protocol. *npj Prim. Care Respir. Med.* **25**, 15051 (2015).

104. Kruis, A. L. *et al.* Primary care COPD patients compared with large pharmaceutically-sponsored COPD studies: An UNLOCK validation study. *PLoS One* **9**, (2014).

105. Chavannes, N. *et al.* UNLOCK: Uncovering and noting long-term outcomes in COPD to enhance knowledge. *Prim. Care Respir. J.* **19**, 408 (2010).

106. Prieto-Centurion, V. *et al.* Multicenter Study Comparing Case Definitions Used to Identify Patients with Chronic Obstructive Pulmonary Disease. *Am. J. Respir. Crit. Care Med.* **190**, 989–995 (2014).

107. Afonso, A. S. M., Verhamme, K. M. C., Sturkenboom, M. C. J. M. & Brusselle, G. G. O. COPD in the general population: Prevalence, incidence and survival. *Respir. Med.* **105**, 1872–1884 (2011).

108. Aaron, S. D. The use of ipratropium bromide for the management of acute asthma exacerbation in adults and children: a systematic review. *J. Asthma* **38**, 521–30 (2001).

109. Peters, S. P. *et al.* Tiotropium bromide step-up therapy for adults with uncontrolled asthma. *N. Engl. J. Med.* **363**, 1715–26 (2010).

110. Goossens, L., Baker, Monz, Zou & Molken, M. Adjusting for COPD severity in database research: developing and validating an algorithm. *Int. J. Chron. Obstruct. Pulmon. Dis.* **13**, 669 (2011).

111. Macaulay, D. *et al.* Development and validation of a claims-based prediction model for COPD severity. *Respir. Med.* **107**, 1568–1577 (2013).

112. Tobe, S. W. *et al.* Harmonization of guidelines for the prevention and treatment of cardiovascular disease: The C-CHANGE Initiative. *Can. Med. Assoc. J.* **183**, 1135–1150 (2011).

113. Tobe, S. W. *et al.* Canadian Cardiovascular Harmonized National Guidelines Endeavour (C-CHANGE): 2014 update. *Can. Med. Assoc. J.* **186**, 1299–1305 (2014).

114. CAN-ADAPTT. Canadian smoking cessation clinical practice guideline. in (Canadian Action Network for the Advancement, Dissemination and Adoption of Practice-informed Tobacco Treatment, 2011).

115. Stone, J., Arthur, H. & Suskin, N. Canadian guidelines for cardiac rehabilitation and cardiovascular disease. Prevention: translating knowledge into action. (2009).

116. Anderson, T., Gregoire, J. & Hegele, R. 2012 update of the Canadian Cardiovascular Society guidelines for the diagnosis and treatment of dyslipidemia for the prevention of cardiovascular disease in the adult. *Can J Cardiol* **29**, 151–67 (2013).

117. Cheng, A. & Lau, D. The Canadian Diabetes Association 2013 clinical practice guidelines — raising the bar and setting higher standards! *Can J Diabetes* **29**, 137–8 (2013).

118. Hackam, D., Quinn, R. & Ravani, P. The 2013 Canadian Hypertension Education Program (CHEP) recommendations for blood pressure measurement, diagnosis, assessment of risk, prevention, and treatment of hypertension. *Can J Cardiol* **29**, 528–42 (2013).

119. Tremblay, M., Warburton, D. & Janssen, I. New Canadian physical activity guidelines. *Appl Physiol Nutr Metab* **36**, 36–46 (2011).

120. Lindsay, M., Gubitz, G. & Bayley, M. Canadian stroke best practice recommendations: overview and methodology. (2013).

121. Lau, D., Douketis, J. & Morrison, K. 2006 Canadian clinical practice guidelines on the management and prevention of obesity in adults and children [summary]. *CMAJ* **176**, S1-13 (2007).

122. Collier, R. National Physician Survey: EMR use at 75%. *Can. Med. Assoc. J.* **187**, E17–E18 (2015).

123. Kotter, T., Blozik, E. & Scherer, M. Methods for the guideline-based development of quality indicators--a systematic review. *Implementation Science* **7**, 21 (2012).

124. Tu, K. *et al.* Quality indicators for the detection and management of chronic kidney disease in primary care in Canada. *C. Open* **5**, E74–E81 (2017).

125. Ivers, N. M. *et al.* Feedback GAP: study protocol for a cluster-randomized trial of goal setting and action plans to increase the effectiveness of audit and feedback interventions in primary care. *Implement Sci* **5**, 98 (2010).

126. Tu, K. *et al.* Diabetics can be identified in an electronic medical record using laboratory tests and prescriptions. *J. Clin. Epidemiol.* **64**, 431–435 (2011).

127. Ivers, N., Pylypenko, B. & Tu, K. Identifying patients with ischemic heart disease in an electronic medical record. *J Prim Care Community Heal.* **2**, 49–53 (2011).

128. Lee, T. M. *et al.* Improving stroke prevention therapy for patients with atrial fibrillation in primary care: protocol for a pragmatic, cluster-randomized trial. *Implement. Sci.* **11**, 159 (2016).

129. Young, J., Ivers, N. M., Jaakkimainen, L., Butt, D. & Tu, K. Identification of Stroke or Transient Ischemic Attack (TIA) Patients Within the Electronic Medical Record Administrative Data Linked Database (EMRALD). in *North American Primary Care Research GroupA* P116 (2014).

130. Johns Hopkins University. Johns Hopkins ACG Case-Mix Adjustment System. Available at: http://www.acg.jhsph.edu. (Accessed: 1st January 2017)

131. Austin, P. C., van Walraven, C., Wodchis, W. P., Newman, A. & Anderson, G. M. Using the Johns Hopkins Aggregated Diagnosis Groups (ADGs) to Predict Mortality in a General Adult Population Cohort in Ontario, Canada. *Med. Care* **49**, 932–939 (2011).

132. McCoy, A. B. *et al.* A framework for evaluating the appropriateness of clinical decision support alerts and responses. *J. Am. Med. Inform. Assoc.* **19**, 346–52 (2012).

133. Braga, M. *et al.* Treatment gaps in the management of cardiovascular risk factors in patients with type 2 diabetes in Canada. *Can. J. Cardiol.* **26**, 297–302 (2010).

134. O'Connor, P. J. *et al.* Impact of electronic health record clinical decision support on diabetes care: a randomized trial. *Ann. Fam. Med.* **9**, 12–21 (2011).

135. Supina, A. L. *et al.* Treatment gaps for hypertension management in rural canadian patients with type 2 diabetes mellitus. *Clin. Ther.* **26**, 598–606 (2004).

136. Lucas, J. E., Bazemore, T. C., Alo, C., Monahan, P. B. & Voora, D. An electronic health record based model predicts statin adherence, LDL cholesterol, and cardiovascular disease in the United States Military Health System. *PLoS One* **12**, 1–17 (2017).

137. Burge, F. I., Bower, K., Putnam, W. & Cox, J. L. Quality indicators for cardiovascular primary care. *Canadian Journal of Cardiology* (2007). doi:10.1016/S0828-282X(07)70772-9

138. Gimpel, N. E., Schoj, V. & Rubinstein, A. Quality management of hypertension in primary care: Do physicians treat patients' blood pressure level or cardiovascular risk? *Qual. Prim. Care* (2006).

139. Padwal, R. S., Bienek, A., McAlister, F. A. & Campbell, N. R. C. Epidemiology of Hypertension in Canada: An Update. *Can. J. Cardiol.* **32**, 687–694 (2016).

140. Public Health Agency of Canada. Tackling Obesity in Canada: Obesity and Excess Weight Rates in Canadian Adults. (2018).

141. Statistics Canada. Obesity in Canadian Adults, 2016 and 2017. (2018). Available at: https://www150.statcan.gc.ca/n1/pub/11-627-m/11-627-m2018033-eng.htm.

142. Quality of Care and Outcomes Research in CVD and Stroke Working Groups. Measuring and Improving Quality of Care. in *Circulation* **101**, 1483–1493 (2000).

143. Sattar, N. & Preiss, D. Screening for diabetes in patients with cardiovascular disease: HbA1c trumps oral glucose tolerance testing. *Lancet Diabetes Endocrinol.* **4**, 560–562 (2016).

144. Florkowski, C. HbA1c as a Diagnostic Test for Diabetes Mellitus - Reviewing the Evidence. *Clin. Biochem. Rev.* **34**, 75–83 (2013).

145. Mannarino, M., Tonelli, M. & Allan, G. M. Tools for practice: screening and diagnosis of type 2 diabetes with HbA1c. *Can. Fam. Physician* **59**, 42 (2013).

146. Sacks, D. B. A1C Versus Glucose Testing: A Comparison. *Diabetes Care* **34**, 518–523 (2011).

147. Camacho, J. E., Shah, V. O., Schrader, R., Wong, C. S. & Burge, M. R. Performance of A1c versus OGTT for the diagnosis of prediabetes in a community-based screening. *Endocr. Pract.* **22**, 1288–1295 (2016).

148. Meijnikman, A. S. *et al.* Not performing an OGTT results in significant underdiagnosis of (pre)diabetes in a high risk adult Caucasian population. *Int. J. Obes.* **41**, 1615–1620 (2017).

149. Bonora, E. & Tuomilehto, J. The Pros and Cons of Diagnosing Diabetes With A1C. *Diabetes Care* **34**, S184–S190 (2011).

150. Hjellestad, I. D., Astor, M. C., Nilsen, R. M., Søfteland, E. & Jonung, T. HbA1c versus oral glucose tolerance test as a method to diagnose diabetes mellitus in vascular surgery patients. *Cardiovasc. Diabetol.* **12**, 79 (2013).

151. Gershon, A. S., Warner, L., Cascagnette, P., Victor, J. C. & To, T. Lifetime risk of developing chronic obstructive pulmonary disease: a longitudinal population study. *Lancet* **378**, 991–996 (2011).

152. Gershon, A. S. *et al.* Health Services Burden of Undiagnosed and Overdiagnosed COPD. *Chest* **153**, 1336–1346 (2018).

153. Hill, K. *et al.* Prevalence and underdiagnosis of chronic obstructive pulmonary disease among patients at risk in primary care. *CMAJ* **182**, 673–678 (2010).

154. Bednarek, M., Maciejewski, J., Wozniak, M., Kuca, P. & Zielinski, J. Prevalence, severity and underdiagnosis of COPD in the primary care setting. *Thorax* **63**, 402–407 (2008).

155. Kaufmann, C. *et al.* Performance measures in the management of chronic obstructive pulmonary disease in primary care - A retrospective analysis. *Praxis (Bern. 1994).* **104**, 897–907 (2015).

156. Heffner, J. E., Mularski, R. A. & Calverley, P. M. A. COPD performance measures: Missing opportunities for improving care. *Chest* **137**, 1181–1189 (2010).

157. Bourbeau, J. *et al.* Practice patterns in the management of chronic obstructive pulmonary disease in primary practice: the CAGE study. *Can. Respir. J.* **15**, 13–19 (2008).

158. National Physician Survey, College of Family Physicians of Canada, Canadian Medical Association & Canada, R. C. of P. and S. of. National Physician Survey. (2014). Available at: http://nationalphysiciansurvey.ca.

159. Asche, C. & Brixner, D. Assessment of COPD-related outcomes via a national electronic medical record database. *Int. J. COPD* **3**, 323–326 (2008).

160. Green, M. E. *et al.* Chronic obstructive pulmonary disease in primary care: an epidemiologic cohort study from the Canadian Primary Care Sentinel Surveillance Network. *C. open* **3**, E15-22 (2015).

161. Lee, T. M., Tu, K., Wing, L. L. & Gershon, A. S. Identifying individuals with physician-diagnosed chronic obstructive pulmonary disease in primary care electronic medical records: a retrospective chart abstraction study. *npj Prim. Care Respir. Med.* **27**, 34 (2017).

162. Jochmann, A. *et al.* General practitioners' adherence to the COPD GOLD guidelines: Baseline data from the Swiss COPD Cohort Study. *Swiss Med. Wkly.* **140**, 1–8 (2010).

163. Terasaki, J., Singh, G., Zhang, W., Wagner, P. & Sharma, G. Using EMR to improve compliance with clinical practice guidelines for management of stable COPD. *Respir. Med.* **109**, 1423–1429 (2015).

164. Gershon, A. S. *et al.* Development of quality indicators for chronic obstructive pulmonary disease (COPD): A modified RAND appropriateness method. *Can. J. Respir. Crit. Care, Sleep Med.* **0**, 1–9 (2018).

165. OntarioMD. Community-Based Physicians Leveraging a Certified EMR Offering. (2019). Available at: https://www.ontariomd.ca/emr-certification/certified-emr-offerings/market-share. (Accessed: 3rd June 2019)

166. Gershon, A. S. *et al.* Chronic Obstructive Pulmonary Disease (COPD) Quality Indicators. *Am J Respir Crit Care Med* **189**, A3043 (2014).

167. Bowen, J. M. *et al.* Pulmonary rehabilitation in Ontario: A cross-sectional survey. *Ont. Health Technol. Assess. Ser.* **15**, 1–67 (2015).

168. Chapman, K., Bourbeau, J. & Rance, L. The burden of COPD in Canada: results from the Confronting COPD survey. *Respir. Med.* **97**, S23–S31 (2003).

169. Asche, C. V. *et al.* Adherence to current guidelines for Chronic Obstructive Pulmonary Disease (COPD) among patients treated with combination of long-acting bronchodilators or inhaled corticosteroids. *Int. J. COPD* **7**, 201–209 (2012).

170. Fitch, K., Iwasaki, K., Pyenson, B., Plauschinat, C. & Zhang, J. Variation in adherence with Global Initiative for Chronic Obstructive Lung Disease (GOLD) drug therapy guidelines: a retrospective actuarial claims data analysis. *Curr. Med. Res. Opin.* **27**, 1425–1429 (2011).

171. Sharif, R., Cuevas, C. R., Wang, Y., Arora, M. & Sharma, G. Guideline adherence in management of stable chronic obstructive pulmonary disease. *Respir. Med.* **107**, 1046–1052 (2013).

172. Nelson, K. E. *et al.* Primary care physician smoking screening and counseling for patients with chronic disease. *Prev. Med. (Baltim).* **71**, 77–82 (2015).

173. Aisanov, Z. *et al.* Primary care physician perceptions on the diagnosis and management of chronic obstructive pulmonary disease in diverse regions of the world. *Int. J. Chron. Obstruct. Pulmon. Dis.* **7**, 271 (2012).

174. Salinas, G. D. *et al.* Barriers to adherence to chronic obstructive pulmonary disease guidelines by primary care physicians. *Int. J. COPD* **6**, 171–179 (2011).

175. Perez, X., Wisnivesky, J. P., Lurslurchachai, L., Kleinman, L. C. & Kronish, I. M. Barriers to adherence to COPD guidelines among primary care providers. *Respir. Med.* **106**, 374–381 (2012).

176. Joo, M. J., Au, D. H., Fitzgibbon, M. L., McKell, J. & Lee, T. A. Determinants of Spirometry Use and Accuracy of COPD Diagnosis in Primary Care. *J. Gen. Intern. Med.* **26**, 1272–1277 (2011).

177. Chavez, P. C. & Shokar, N. K. Diagnosis and management of chronic obstructive

pulmonary disease (COPD) in a primary care clinic. *COPD J. Chronic Obstr. Pulm. Dis.* **6**, 446–451 (2009).

178. Soler, N. *et al.* Changes in management of chronic obstructive pulmonary disease (COPD) in primary care: EMMEPOC study. *Respir. Med.* **104**, 67–75 (2010).

179. Meeraus, W. *et al.* COPD treatment pathways in France: a retrospective analysis of electronic medical record data from general practitioners. *Int. J. Chron. Obstruct. Pulmon. Dis.* **Volume 14**, 51–63 (2018).

180. Rothnie, K. J., Chandan, J. S., Goss, H. G., Müllerová, H. & Quint, J. K. Validity and interpretation of spirometric recordings to diagnose COPD in UK primary care. *Int. J. COPD* **12**, 1663–1668 (2017).

181. Nielsen, L. O., Olsen, S., Jarbøl, D. E. & Pedersen, M. L. Spirometry in Greenland: A cross-sectional study on patients treated with medication targeting obstructive pulmonary disease. *Int. J. Circumpolar Health* **75**, 1–6 (2016).

182. Price, D. *et al.* Management of COPD in the UK primary-care setting: an analysis of real-life prescribing patterns. *Int. J. Chron. Obstruct. Pulmon. Dis.* **9**, 889 (2014).

183. Tsagaraki, V., Markantonis, S. L. & Amfilochiou, A. Pharmacotherapeutic management of COPD patients in Greece – adherence to international guidelines. *J. Clin. Pharm. Ther.* **31**, 369–374 (2006).

184. Hull, S., Mathur, R., Lloyd-Owen, S., Round, T. & Robson, J. Improving outcomes for people with COPD by developing networks of general practices: evaluation of a quality improvement project in east London. *npj Prim. Care Respir. Med.* **24**, 14082 (2014).

185. Mahlknecht, A. *et al.* Improving quality of care in general practices by self-audit, benchmarking and quality circles. *Wien. Klin. Wochenschr.* **128**, 706–718 (2016).

186. Ferrara, R. *et al.* Improvement in the management of chronic obstructive pulmonary disease following a clinical educational program: results from a prospective cohort study in the Sicilian general practice setting. *npj Prim. Care Respir. Med.* **28**, 10 (2018).

187. Joo, M. J., Lee, T. A. & Weiss, K. B. Geographic Variation of Spirometry Use in Newly Diagnosed COPD*. *Chest* **134**, 38–45 (2008).

188. Nishi, S. P. E., Wang, Y., Kuo, Y., Goodwin, J. S. & Sharma, G. Spirometry Use among Older Adults with Chronic Obstructive Pulmonary Disease: 1999–2008. *Ann. Am. Thorac. Soc.* **10**, 565–573 (2013).

189. Moore, P. L. Practice Management and Chronic Obstructive Pulmonary Disease in Primary Care. *Am. J. Med.* **120**, 23–27 (2007).

190. Gershon, A. S., Hwee, J., Croxford, R., Aaron, S. D. & To, T. Patient and physician factors associated with pulmonary function testing for COPD : A population study. *Chest* **145**, 272–281 (2014).

191. Steurer-Stey, C., Dallalana, K., Jungi, M. & Rosemann, T. Management of chronic obstructive pulmonary disease in Swiss primary care: Room for improvement. *Qual. Prim. Care* **20**, 365–373 (2012).

192. Mapel, D. W. *et al.* Utilization in COPD. *Chest* **117**, 346S-353S (2000).

193. Yawn, B. P. *et al.* Spirometry can be done in family physicians' offices and alters clinical

decisions in management of asthma and COPD*. *Chest* **132**, 1162–1168 (2007).

194. Licskai, C. J., Sands, T. W., Paolatto, L., Nicoletti, I. & Ferrone, M. Spirometry in Primary Care: An Analysis of Spirometry Test Quality in a Regional Primary Care Asthma Program. *Can. Respir. J.* **19**, 249–254 (2012).

195. Gershon, A. *et al.* Outcomes of patients with chronic obstructive pulmonary disease diagnosed with or without pulmonary function testing. *Can. Med. Assoc. J.* **189**, E530–E538 (2017).

196. Burkes, R. *et al.* Impact of Quality Improvement on Care of Chronic Obstructive Pulmonary Disease Patients in an Internal Medicine Resident Clinic. *Healthcare* **6**, 88 (2018).

197. Jones, R. & Roberts, M. National cohort data from Sweden to the national COPD audit in England and Wales: Grand designs for quality improvement. *Prim. Care Respir. J.* **23**, 7–8 (2014).

198. Lee, T. A., Weaver, F. M. & Weiss, K. B. Impact of pneumococcal vaccination on pneumonia rates in patients with COPD and asthma. *J. Gen. Intern. Med.* **22**, 62–67 (2007).

199. Froes, F., Roche, N. & Blasi, F. Pneumococcal vaccination and chronic respiratory diseases. *Int. J. Chron. Obstruct. Pulmon. Dis.* **Volume 12**, 3457–3468 (2017).

200. Carreño-Ibáñez, L. V. *et al.* Coverage of and factors associated with pneumococcal vaccination in chronic obstructive pulmonary disease. *Int. J. Tuberc. Lung Dis.* **19**, 735–741 (2015).

201. Giese, C. *et al.* Low vaccination coverage for seasonal influenza and pneumococcal disease among adults at-risk and health care workers in Ireland, 2013: The key role of GPs in recommending vaccination. *Vaccine* **34**, 3657–3662 (2016).

202. Steens, A., Vestrheim, D. F., Freiesleben, B. & Blasio, D. Pneumococcal vaccination in older adults in the era of childhood vaccination : Public health insights from a Norwegian statistical prediction study. *Epidemics* **11**, 24–31 (2015).

203. Guthmann, J.-P., Fonteneau, L., Bonmarin, I. & Lévy-Bruhl, D. Enquête nationale de couverture vaccinale, France, janvier 2011. Couverture vaccinale contre la grippe saisonnière dans les groupes cibles et mesure de l'efficacité vaccinale. Couverture vaccinale par les vaccins diphtérie-tétanos-poliomyélite (dTP) et an. 21 (2011).

204. Schneeberg, A. *et al.* Knowledge, attitudes, beliefs and behaviours of older adults about pneumococcal immunization, a Public Health Agency of Canada/Canadian Institutes of Health Research Influenza Research Network (PCIRN) investigation. *BMC Public Health* **14**, 442 (2014).

205. Walters JAE, Tang JNQ, Poole P, W.-B. R. Pneumococcal vaccines for preventing pneumonia in chronic obstructive pulmonary disease (Review) Copyright © 2018 The Cochrane Collaboration. Published by John Wiley & Sons, Ltd. 2. **21**, (2018).

206. Sehatzadeh, S. Influenza and pneumococcal vaccinations for patients with chronic obstructive pulmonary disease (COPD): an evidence-based review (Structured abstract). *Database Abstr. Rev. Eff.* **2**, 2 (2015).

207. Roberts, D. H. *et al.* Design and Measurement of Quality Improvement Indicators in

Ambulatory Pulmonary Care. *Chest* **136**, 1134–1140 (2009).

208. Desai, S. P. *et al.* Increasing pneumococcal vaccination for immunosuppressed patients: A cluster quality improvement trial. *Arthritis Rheum.* **65**, 39–47 (2013).

209. Ontario Ministry of Health and Long-Term Care. Universal Influenza Immunization Program (UIIP). Available at: http://www.health.gov.on.ca/en/pro/programs/publichealth/flu/uiip/prequalification.aspx. (Accessed: 5th May 2019)

210. White, P., Thornton, H., Pinnock, H., Georgopoulou, S. & Booth, H. P. Overtreatment of COPD with Inhaled Corticosteroids - Implications for Safety and Costs: Cross-Sectional Observational Study. *PLoS One* **8**, e75221 (2013).

211. Linder, J. A. *et al.* An Electronic Health Record–Based Intervention to Improve Tobacco Treatment in Primary Care. *Arch. Intern. Med.* **169**, 781 (2009).

212. Bae, J., Ford, E. W., Kharrazi, H. H. K. & Huerta, T. R. Electronic medical record reminders and smoking cessation activities in primary care. *Addict. Behav.* **77**, 203–209 (2018).

213. Boyle, R., Solberg, L. & Fiore, M. Use of electronic health records to support smoking cessation (Review) SUMMARY OF FINDINGS FOR THE MAIN COMPARISON. (2014). doi:10.1002/14651858.CD008743.pub3.www.cochranelibrary.com

214. Alabousi, M. *et al.* Cardiovascular Risk Factor Management Performance in Canada and the United States: A Systematic Review. *Can. J. Cardiol.* **33**, 393–404 (2017).

215. Tobe, S. W. *et al.* Canadian Cardiovascular Harmonized National Guidelines Endeavour (C-CHANGE) guideline for the prevention and management of cardiovascular disease in primary care: 2018 update. *Can. Med. Assoc. J.* **190**, E1192–E1206 (2018).

216. Lee, T. M. *et al.* Measuring Cardiovascular Quality in Primary Care Using Canadian Cardiovascular Harmonization of National Guidelines Endeavour and Electronic Medical Record Data in Ontario. *CJC Open* **1**, 1–9 (2019).

217. Tu, J. V. *et al.* The Cardiovascular Health in Ambulatory Care Research Team performance indicators for the primary prevention of cardiovascular disease: a modified Delphi panel study. *C. Open* **5**, E315–E321 (2017).

218. Tu, J. V. *et al.* Regional variations in ambulatory care and incidence of cardiovascular events. *Can. Med. Assoc. J.* **189**, E494–E501 (2017).

219. Schultz, S. E., Rothwell, D. M., Chen, Z. & Tu, K. Identifying cases of congestive heart failure from administrative data: a validation study using primary care patient records. *Chronic Dis. Inj. Can.* **33**, 160–6 (2013).

220. Hurvich, C. M. & Tsai, C. L. Bias of the corrected aic criterion for underfitted regression and time series models. *Biometrika* **78**, 499–509 (1991).

221. Rose, S. A., Turchin, A., Grant, R. W. & Meigs, J. B. Documentation of body mass index and control of associated risk factors in a large primary care network. *BMC Health Serv. Res.* **9**, 236 (2009).

222. Ridker, P. M. *et al.* A Randomized Trial of Low-Dose Aspirin in the Primary Prevention of Cardiovascular Disease in Women. *N. Engl. J. Med.* **352**, 1293–1304 (2005).

223. Renda, G. *et al.* Thrombotic and hemorrhagic burden in women: Gender-related issues in the response to antithrombotic therapies. *Int. J. Cardiol.* **286**, 198–207 (2019).

224. Patti, G. *et al.* Platelet function and long-term antiplatelet therapy in women: Is there a gender-specificity? A state-of-the-art paper. *Eur. Heart J.* **35**, 2213–2223 (2014).

225. Straus, S. E., Majumdar, S. R. & McAlister, F. A. New Evidence for Stroke Prevention. *JAMA* **288**, 1388 (2002).

226. Nash, D. *et al.* Improving Care for Patients with or at Risk for Chronic Kidney Disease using Electronic Medical Record Interventions: A Pragmatic Cluster Randomized Trial Protocol. *Can. J. Kidney Heal. Dis.* (2017).

227. Pope, C., Ziebland, S. & Mays, N. Qualitative research in health care - Analysing qualitative data. *Br. Med. J.* **320**, 114–116 (2000).

228. Creswell, J. W. Creswell, J.W. (2003). Chapter One, "A Framework for Design." *Res. Des. Qual. Quant. Mix. methods approaches* 3–26 (2003). doi:10.3109/08941939.2012.723954

229. Rogers, E. M. *Diffusion of innovations*. *Macmillian Publishing Co.* (1995). doi:citeulike-article-id:126680

230. de Grood, C., Raissi, A., Kwon, Y. & Santana, M. J. Adoption of e-health technology by physicians: A scoping review. *J. Multidiscip. Healthc.* **9**, 335–344 (2016).

231. Devaraj, S., Sharma, S. K., Fausto, D. J., Viernes, S. & Kharrazi, H. Barriers and Facilitators to Clinical Decision Support Systems Adoption: A Systematic Review. *J. Bus. Adm. Res.* **3**, (2014).

232. Ajami, S. & Bagheri-Tadi, T. Barriers for adopting electronic health records (EHRs) by physicians. *Acta Inform. Medica* (2013). doi:10.5455/aim.2013.21.129-134

233. Dünnebeil, S., Sunyaev, A., Blohm, I., Leimeister, J. M. & Krcmar, H. Determinants of physicians' technology acceptance for e-health in ambulatory care. *Int. J. Med. Inform.* (2012). doi:10.1016/j.ijmedinf.2012.02.002

234. Vedel, I. *et al.* Healthcare professionals' adoption and use of a clinical information system (CIS) in primary care: Insights from the Da Vinci study. *Int. J. Med. Inform.* (2012). doi:10.1016/j.ijmedinf.2011.11.002

235. Holden, R. J. What stands in the way of technology-mediated patient safety improvements? A study of facilitators and barriers to physicians' use of electronic health records. *J. Patient Saf.* (2011). doi:10.1097/PTS.0b013e3182388cfa

236. Hackl, W., Hoerbst, A. & Ammenwerth, E. 'Why the hell do we need electronic health records?': EHR acceptance among physicians in private practice in Austria: A qualitative study. *Methods Inf. Med.* (2011). doi:10.3414/ME10-02-0020

237. Hier, D. B., Rothschild, A., LeMaistre, A. & Keeler, J. Differing faculty and housestaff acceptance of an electronic health record. *Int. J. Med. Inform.* (2005). doi:10.1016/j.ijmedinf.2005.03.006

238. Chock, G. & Perna, G. Soul road: one solo doc's extensive EMR journey implementing an EMR is a long process fraught with obstacles, especially for a solo practitioner. *Healthc. Inform.* (2014).

239. Russ, A. L., Zillich, A. J., McManus, M. S., Doebbeling, B. N. & Saleem, J. J. A human factors investigation of medication alerts: barriers to prescriber decision-making and clinical workflow. *AMIA Annu. Symp. Proc.* (2009).

240. Thorn, S. A., Carter, M. A. & Bailey, J. E. Emergency Physicians' Perspectives on Their Use of Health Information Exchange. *Ann. Emerg. Med.* **63**, 329–337 (2014).

241. Yau, G. L., Williams, A. S. & Brown, J. B. Family physicians' perspectives on personal health records: Qualitative study. *Can. Fam. Physician* (2011).

242. Morton, M. E. & Wiedenbeck, S. A framework for predicting EHR adoption attitudes: a physician survey. *Perspect. Health Inf. Manag.* (2009).

243. Pizzi, L. T., Suh, D. C., Barone, J. & Nash, D. B. Factors related to physicians' adoption of electronic prescribing: Results from a national survey. *American Journal of Medical Quality* (2005). doi:10.1177/1062860604273775

244. Greiver, M., Barnsley, J., Glazier, R. H., Moineddin, R. & Harvey, B. J. Implementation of electronic medical records: Theory-informed qualitative study. *Can. Fam. Physician* (2011).

245. Brooks, E., Turvey, C. & Augusterfer, E. F. Provider barriers to telemental health: Obstacles overcome, obstacles remaining. *Telemed. e-Health* (2013). doi:10.1089/tmj.2013.0068

246. Iqbal, U. *et al.* The relationship between usage intention and adoption of electronic health records at primary care clinics. *Comput. Methods Programs Biomed.* **112**, 731–737 (2013).

247. Chen, R. F. & Hsiao, J. L. An investigation on physicians' acceptance of hospital information systems: A case study. *Int. J. Med. Inform.* (2012). doi:10.1016/j.ijmedinf.2012.05.003

248. Trafton, J. *et al.* Evaluation of the acceptability and usability of a decision support system to encourage safe and effective use of opioid therapy for chronic, noncancer pain by primary care providers. *Pain Med.* (2010). doi:10.1111/j.1526-4637.2010.00818.x

249. Marcy, T. W., Skelly, J., Shiffman, R. N. & Flynn, B. S. Facilitating adherence to the tobacco use treatment guideline with computer-mediated decision support systems: Physician and clinic office manager perspectives. *Prev. Med. (Baltim).* (2005). doi:10.1016/j.ypmed.2004.11.026

250. Toth-Pal, E., Wårdh, I., Strender, L. E. & Nilsson, G. Implementing a clinical decision-support system in practice: A qualitative analysis of influencing attitudes and characteristics among general practitioners. *Informatics Heal. Soc. Care* (2008). doi:10.1080/17538150801956754

251. Subramanian, S. *et al.* Computerized physician order entry with clinical decision support in long-term care facilities: Costs and benefits to stakeholders. *J. Am. Geriatr. Soc.* (2007). doi:10.1111/j.1532-5415.2007.01304.x

252. Robertson, J. *et al.* Electronic information and clinical decision support for prescribing: State of play in Australian general practice. *Fam. Pract.* (2011). doi:10.1093/fampra/cmq031

253. Straus, S. G., Chen, A. H., Yee, H., Kushel, M. B. & Bell, D. S. Implementation of an

electronic referral system for outpatient specialty care. *AMIA Annu. Symp. Proc.* (2011).

254. Vishwanath, A. & Scamurra, D. S. Barriers to the adoption of electronic health records: Using concept mapping to develop a comprehensive empirical model. *Health Informatics J.* (2007). doi:10.1177/1460458207076468

255. Olenik, K. & Lehr, B. Counteracting brain drain of health professionals from rural areas via teleconsultation: Analysis of the barriers and success factors of teleconsultation. *J. Public Heal.* (2013). doi:10.1007/s10389-013-0565-8

256. Valdes, I., Kibbe, D. C., Tolleson, G., Kunik, M. E. & Petersen, L. A. Barries to proliferation of electronic medical records. *Inform. Prim. Care* (2004). doi:10.14236/jhi.v12i1.102

257. Badran, H., Pluye, P. & Grad, R. Advantages and disadvantages of educational email alerts for family physicians: Viewpoint. *Journal of Medical Internet Research* (2015). doi:10.2196/jmir.3773

258. Menachemi, N. Barriers to ambulatory EHR: Who are 'imminent adopters' and how do they differ from other physicians? *Inform. Prim. Care* (2006). doi:10.14236/jhi.v14i2.620

259. Villalba-Mora, E., Casas, I., Lupiañez-Villanueva, F. & Maghiros, I. Adoption of health information technologies by physicians for clinical practice: The Andalusian case. *Int. J. Med. Inform.* (2015). doi:10.1016/j.ijmedinf.2015.03.002

260. Terry, A. L., Giles, G., Brown, J. B., Thind, A. & Stewart, M. Adoption of electronic medical records in family practice: the providers' perspective. *Fam. Med.* **41**, 508–512 (2009).

261. Davidson, E., Simpson, C. R., Demiris, G., Sheikh, A. & McKinstry, B. Integrating Telehealth Care-Generated Data With the Family Practice Electronic Medical Record: Qualitative Exploration of the Views of Primary Care Staff. *Interact. J. Med. Res.* (2013). doi:10.2196/ijmr.2820

262. Dikomitis, L., Green, T. & Macleod, U. Embedding electronic decision-support tools for suspected cancer in primary care: a qualitative study of GPs' experiences. *Prim. Health Care Res. Dev.* (2015). doi:10.1017/S1463423615000109

263. Jamoom, E. W., Patel, V., Furukawa, M. F. & King, J. EHR adopters vs. non-adopters: Impacts of, barriers to, and federal initiatives for EHR adoption. *Healthcare* (2014). doi:10.1016/j.hjdsi.2013.12.004

264. Holmes, C., Brown, M., Hilaire, D. S. & Wright, A. Healthcare provider attitudes towards the problem list in an electronic health record: a mixed-methods qualitative study. *BMC Med. Inform. Decis. Mak.* **12**, 127 (2012).

265. Sullivan-Taylor, P., Webster, G., Mukhi, S. & Sanchez, M. Development of electronic medical record content standards to collect pan-Canadian Primary Health Care indicator data. *Stud. Health Technol. Inform.* **143**, 167–73 (2009).

266. Canadian Institute for Health Information. *Canadian Institute for Health Information Primary Health Care Indicators Electronic Medical Record Content Standards, Version 1.1*. (CIHI, 2009).

267. Canadian Institute for Health Information. *Draft Pan-Canadian Primary Health Care Electronic Medical Record Content Standard, Version 2.0—Business View*. (2011).

268. Canadian Institute for Health Information. *Pan-Canadian Primary Health Care Electronic Medical Record Content Standard, Version 3.0*. (2014).

269. MacPherson, A. *et al.* Pan-Canadian asthma and COPD standards for electronic health records: A Canadian Thoracic Society Expert Working Group Report. *Can. J. Respir. Crit. Care, Sleep Med.* **2**, 244–250 (2018).

270. Hoffman, M. A. & Williams, M. S. Electronic medical records and personalized medicine. *Hum. Genet.* **130**, 33–39 (2011).

271. Sitapati, A. *et al.* Integrated precision medicine: the role of electronic health records in delivering personalized treatment. *Wiley Interdiscip. Rev. Syst. Biol. Med.* **9**, e1378 (2017).

272. Canadian Institute for Health Information (CIHI). How Canada Compares: Results From The Commonwealth Fund 2015 International Health Policy Survey of Primary Care Physicians. (2016).

273. Barkhuysen, P. *et al.* Is the quality of data in an electronic medical record sufficient for assessing the quality of primary care? *J. Am. Med. Inform. Assoc.* **21**, 692–298 (2014).

274. Wu, A. W. *et al.* Clinical Practice Guidelines and Quality of Care for Older Patients With Multiple Comorbid Diseases. *Jama* **294**, 716 (2005).

275. Meltzer, D. O. & Chung, J. W. The population value of quality indicator reporting: A framework for prioritizing health care performance measures. *Health Aff.* **33**, 132–139 (2014).

276. Ten Asbroek, A. *et al.* Developing a national performance indicator framework for the Dutch health system. *Int. J. Qual. Heal. Care* **16**, 65–72 (2004).

277. Hutchison, B. *et al. Quality in Primary Care: Final Report of the Quality Working Group to the Primary Healthcare Planning Group*. (2011).

278. Schoen, C., Osborn, R., Squires, D. & Doty, M. M. Access, affordability, and insurance complexity are often worse in the united states compared to ten other countries. *Health Aff.* **32**, 2205–2215 (2013).

279. Handler, A., Issel, M. & Turnock, B. A conceptual framework to measure performance of the public health system. *Am. J. Public Health* **91**, 1235–9 (2001).

280. Maher, D. The power of health information--the use of cohort monitoring in managing patients with chronic non-communicable diseases. *Trop. Med. Int. Health* **17**, 1567–1568 (2012).

281. University of Toronto Department of Family & Community Medicine. About UTOPIAN. Available at: https://www.dfcm.utoronto.ca/about-utopian. (Accessed: 25th September 2019)

Appendices

Appendix A Search terms used for the literature in this thesis

PubMed Search terms with medical subject heading (MeSH) terms

Concept	Search terms
Overall search strategy	(Health condition as below) AND ([Mesh: EMR] or tool) AND ('quality improvement' OR 'performance measurement' OR epidemiology OR public health) AND primary care
EMR terms:	("Medical Records"[Mesh] OR "Electronic Health Records"[Mesh] OR "Medical Record Linkage"[Mesh] AND "Medical Records Systems, Computerized"[Mesh])
Quality improvement terms:	("Quality Improvement"[Mesh] OR "Meaningful Use"[Mesh] OR "Total Quality Management"[Mesh] OR "Public Health Surveillance"[Mesh] OR "Public Health Informatics"[Mesh] OR "Clinical Audit"[Mesh] OR "Medical Audit"[Mesh] OR "Quality Assurance, Health Care"[Mesh] OR "Benchmarking"[Mesh] OR "Management Audit"[Mesh] OR "Quality of Health Care"[Mesh] OR "Practice Patterns, Physicians'"[Mesh])
Primary care	("Primary Health Care"[Mesh] OR "Physicians, Primary Care"[Mesh] OR "Physicians, Family"[Mesh] OR "General Practitioners"[Mesh])
Epidemiology	"Epidemiologic Methods"[Mesh] OR
Without disease	("Medical Records"[Mesh] OR "Electronic Health Records"[Mesh] OR "Medical Record Linkage"[Mesh] AND "Medical Records Systems, Computerized"[Mesh]) AND

Concept	Search terms
	("Quality Improvement"[Mesh] OR "Meaningful Use"[Mesh] OR "Total Quality Management"[Mesh] OR "Public Health Surveillance"[Mesh] OR "Public Health Informatics"[Mesh] OR "Clinical Audit"[Mesh] OR "Medical Audit"[Mesh] OR "Quality Assurance, Health Care"[Mesh] OR "Benchmarking"[Mesh] OR "Management Audit"[Mesh] OR "Quality of Health Care"[Mesh] OR "Practice Patterns, Physicians'"[Mesh]) AND ("Primary Health Care"[Mesh] OR "Physicians, Primary Care"[Mesh] OR "Physicians, Family"[Mesh] OR "General Practitioners"[Mesh])
With disease	("Medical Records"[Mesh] OR "Electronic Health Records"[Mesh] OR "Medical Record Linkage"[Mesh] AND "Medical Records Systems, Computerized"[Mesh]) AND ("Quality Improvement"[Mesh] OR "Meaningful Use"[Mesh] OR "Total Quality Management"[Mesh] OR "Public Health Surveillance"[Mesh] OR "Public Health Informatics"[Mesh] OR "Clinical Audit"[Mesh] OR "Medical Audit"[Mesh] OR "Quality Assurance, Health Care"[Mesh] OR "Benchmarking"[Mesh] OR "Management Audit"[Mesh] OR "Quality of Health Care"[Mesh] OR "Practice Patterns, Physicians'"[Mesh]) AND ("Primary Health Care"[Mesh] OR "Physicians, Primary Care"[Mesh] OR "Physicians, Family"[Mesh] OR "General Practitioners"[Mesh]) AND ("Pulmonary Disease, Chronic Obstructive"[Mesh] OR "COPD, Severe Early-Onset" [Supplementary Concept] OR "Cardiovascular Diseases"[Mesh] OR "Vascular Diseases"[Mesh] OR "Atrial Fibrillation"[Mesh] OR "Stroke"[Mesh])

PubMed Search Results

Search target	Number of results	Search terms
Overall	Results: 290	("Medical Records"[Mesh] OR "Electronic Health Records"[Mesh] OR "Medical Record Linkage"[Mesh] AND "Medical Records Systems, Computerized"[Mesh]) AND ("Quality Improvement"[Mesh] OR "Meaningful Use"[Mesh] OR "Total Quality Management"[Mesh] OR "Public Health Surveillance"[Mesh] OR "Public Health Informatics"[Mesh] OR "Clinical Audit"[Mesh] OR "Medical Audit"[Mesh] OR "Quality Assurance, Health Care"[Mesh] OR "Benchmarking"[Mesh] OR "Management Audit"[Mesh] OR "Quality of Health Care"[Mesh] OR "Practice Patterns, Physicians'"[Mesh]) AND ("Primary Health Care"[Mesh] OR "Physicians, Primary Care"[Mesh] OR "Physicians, Family"[Mesh] OR "General Practitioners"[Mesh]) AND ("Pulmonary Disease, Chronic Obstructive"[Mesh] OR "COPD, Severe Early-Onset" [Supplementary Concept] OR "Cardiovascular Diseases"[Mesh] OR "Vascular Diseases"[Mesh] OR "Atrial Fibrillation"[Mesh] OR "Stroke"[Mesh] OR "Diabetes Mellitus"[Mesh])
COPD-specific	Results: 18	("Medical Records"[Mesh] OR "Electronic Health Records"[Mesh] OR "Medical Record Linkage"[Mesh] AND "Medical Records Systems, Computerized"[Mesh]) AND ("Quality Improvement"[Mesh] OR "Meaningful Use"[Mesh] OR "Total Quality Management"[Mesh] OR "Public Health Surveillance"[Mesh] OR "Public Health Informatics"[Mesh] OR "Clinical Audit"[Mesh] OR "Medical Audit"[Mesh] OR "Quality Assurance, Health

		Care"[Mesh] OR "Benchmarking"[Mesh] OR "Management Audit"[Mesh] OR "Quality of Health Care"[Mesh] OR "Practice Patterns, Physicians'"[Mesh]) AND ("Primary Health Care"[Mesh] OR "Physicians, Primary Care"[Mesh] OR "Physicians, Family"[Mesh] OR "General Practitioners"[Mesh]) AND ("Pulmonary Disease, Chronic Obstructive"[Mesh] OR "COPD, Severe Early-Onset" [Supplementary Concept])
Cardiovascular disease specific	Results: 174	("Medical Records"[Mesh] OR "Electronic Health Records"[Mesh] OR "Medical Record Linkage"[Mesh] AND "Medical Records Systems, Computerized"[Mesh]) AND ("Quality Improvement"[Mesh] OR "Meaningful Use"[Mesh] OR "Total Quality Management"[Mesh] OR "Public Health Surveillance"[Mesh] OR "Public Health Informatics"[Mesh] OR "Clinical Audit"[Mesh] OR "Medical Audit"[Mesh] OR "Quality Assurance, Health Care"[Mesh] OR "Benchmarking"[Mesh] OR "Management Audit"[Mesh] OR "Quality of Health Care"[Mesh] OR "Practice Patterns, Physicians'"[Mesh]) AND ("Primary Health Care"[Mesh] OR "Physicians, Primary Care"[Mesh] OR "Physicians, Family"[Mesh] OR "General Practitioners"[Mesh]) AND ("Cardiovascular Diseases"[Mesh] OR "Vascular Diseases"[Mesh] OR "Atrial Fibrillation"[Mesh] OR "Stroke"[Mesh])
Diabetes specific	Results: 145	("Medical Records"[Mesh] OR "Electronic Health Records"[Mesh] OR "Medical Record Linkage"[Mesh] AND "Medical Records Systems, Computerized"[Mesh]) AND ("Quality Improvement"[Mesh] OR "Meaningful Use"[Mesh] OR "Total Quality Management"[Mesh] OR

		"Public Health Surveillance"[Mesh] OR "Public Health Informatics"[Mesh] OR "Clinical Audit"[Mesh] OR "Medical Audit"[Mesh] OR "Quality Assurance, Health Care"[Mesh] OR "Benchmarking"[Mesh] OR "Management Audit"[Mesh] OR "Quality of Health Care"[Mesh] OR "Practice Patterns, Physicians'"[Mesh]) AND ("Primary Health Care"[Mesh] OR "Physicians, Primary Care"[Mesh] OR "Physicians, Family"[Mesh] OR "General Practitioners"[Mesh]) AND ("Diabetes Mellitus"[Mesh])

#	Search	**Reason**	**Number of results**
1	**medical records systems, computerized (exp)**	to capture concepts including electronic health records, electronic medical records, medical information system, clinical information systems	22,977
2	**medical record linkage (exp), population surveillance (exp)**,	administrative data, external databases, surveillance database	44,867
3	**vascular diseases (exp)**,	hypertension, stroke, acute myocardial infarction, peripheral arterial disease, cardiovascular disease,	719.693

#	Search	**Reason**	**Number of results**
4	**1 AND 2 AND 3**	Targeted search	31

Medline database: ‘Ovid 1996 to 2014 Ovid MEDLINE® without Revisions’

Date of search: Februay 2016
Sources: peer reviewed journals, trade journals, trade magazine articles,
Languages: English
Countries: All

Appendix B Description of C-CHANGE recommendation and adapted quality indicators, numerators and denominators

ID	Description	Original recommendation	Adapted quality indicator	Lookback period	Numerator *n*	Denominator *n*	Overall rate in EMRALD® %
Domain: Body Habitus (1 to 3)							
1	Adult BMI	Height, weight and waist circumference should be measured, and body mass index calculated for all adults	% of adults who have a **BMI recorded in the EMR**	All time	156,292	233,081	67.1%
2	Healthy BMI	Maintenance of a healthy body weight (body mass index 18.5 to 24.9 kg/m2, and waist circumference less than 102 cm for men and less than 88 cm for women) is recommended for non-hypertensive individuals to prevent hypertension and for hypertensive patients to reduce blood pressure. All overweight hypertensive individuals should be advised to lose weight.	% of adults with a recorded BMI whose latest **BMI in the normal range** (18.5 to 24.9kg/m2)	All time	53,257	156,292	34.1%
3	Children's BMI	Measuring body mass index (BMI = weight[kg]/height[m]2) in children aged two to seventeen years	% of children aged 2-17 years **who have BMI recorded**	3 years	27,414	45,455	60.3%

ID	Description	Original recommendation	Adapted quality indicator	Lookback period	Numerator *n*	Denominator *n*	Overall rate in EMRALD® %
Domain: Risk Factor Screening (4 to 8)							
4	Diabetes screening	Screening for diabetes using FPG and/or HbA1c should be performed every 3 years in individuals ≥ 40 years of age or at high risk using a risk calculator. More frequent and/or earlier testing with either FPG and/or HbA1c or 2hPG in a 75 g OGTT should be considered in those at very high risk using a risk calculator or in people with additional risk factors for diabetes. • History of prediabetes (IGT, IFG, or A1C 6.0%-6.4%); History of gestational diabetes mellitus; • History of delivery of a macrosomic infant; • Presence of vascular risk factors (low HDL <1.0 mmol/L in males, < 1.3 mmol/L in females, high triglycerides > 1.7 mmol/L, hypertension, overweight/obesity); • Presence of associated diseases (polycystic ovary syndrome, acanthosis nigricans, obstructive sleep apnoea, psychiatric disorders, HIV infection); • Use of drugs associated with diabetes (glucocorticoids, atypical antipsychotics, HAART)	% of adults aged ≥41 without diabetes **who have FPG or HbA1c results**	3 years	60,519	127,786	47.4%
5	Diabetes screening with 2hPG (I)	Testing with 2hPG in a 75 g OGTT should be undertaken in individuals with FPG 6.1-6.9 mmol/L and/or HbA1c 6.0%-6.4% in order to identify individuals with IGT or diabetes	% of adults with FPG of 6.1-6.9mmol/L or HbA1c 6.0-6.4% **who have a 2hPG test** (excluding patients with diabetes)	All time	2,184	23,267	9.4%

ID	Description	Original recommendation	Adapted quality indicator	Lookback period	Numerator *n*	Denominator *n*	Overall rate in EMRALD® %
6	Diabetes screening with 2hPG (II)	Testing with 2hPG in a 75 g OGTT may be undertaken in individuals with FPG 5.6-6.0 mmol/L and/or HbA1c 5.5%-5.9% and ≥ 1 risk factor(s) in order to identify individuals with IGT or diabetes.	% of adults with FPG 5.6-6.0mmol/L or HbA1c 5.5-5.9%, **who have a 2hPG test** (excluding patients with diabetes)	All time	2,786	63,454	4.4%
7	Lipid screening	Screening of plasma lipids is recommended in adult men > 40 and women > 50 years of age or postmenopausal. Screen lipids at any age for: smoking, diabetes, hypertension, overweight, rheumatoid arthritis, systemic lupus erythematosis, psoriatic arthritis, ankylosing spondylitis, inflammatory bowel disease, chronic obstructive pulmonary disease, chronic HIV infection, CKD, abdominal aneurysm and erectile dysfunction. Consider screening individuals of First Nations or South Asian ancestry at an earlier age.	% of men over age 41; women over age 51; or have diabetes, hypertension, CKD, currently smoke, or are overweight, **who have a lipid test**	3 years	109,954	160,065	68.7%
8	Smoking history	All patients/clients should be asked if they use tobacco and should have their tobacco use status documented on a regular basis. All physicians, nurses and other health care workers should strongly advise all patients who smoke to quit and provide brief advice.	% of adult patients with smoking status recorded in the EMR	All time	142,078	233,081	61.0%

ID	Description	Original recommendation	Adapted quality indicator	Lookback period	Numerator *n*	Denominator *n*	Overall rate in EMRALD® %
Domain: Diagnostic Strategies (9 to 10))							
9a	Screening with FBG and ECG for hypertensive patients	Routine laboratory tests that should be performed for the investigation of all patients with hypertension include: urinalysis; blood chemistry (potassium, sodium and creatinine); fasting blood glucose; fasting serum total cholesterol and high density lipoprotein cholesterol, low density lipoprotein cholesterol and triglycerides; and standard 12-lead electrocardiography	% of adults with hypertension who **have a test for potassium**	All time	45,063	48,965	92.0%
9b			% of adults with hypertension who **have a test for sodium**	All time	44,777	48,965	91.4%
9c			% of adults with hypertension who **have a test for creatinine**	All time	46,593	48,965	95.2%
9d			% of adults with hypertension who have a test for **fasting blood glucose**	All time	27,849	48,965	56.9%
9e			% of adults with hypertension who **have a lipid profile test**	All time	45,021	48,965	91.9%
9f			% of adults with hypertension who **have a record of ECG**	All time	27,202	48,965	55.6%
10	Liver enzyme tests for overweight patients	Additional investigations, such as liver enzyme tests, urinalysis and sleep studies (when appropriate), to screen for and exclude other common overweight/obesity-related health problems.	% of adults who are overweight (BMI > 25kg/m2) **who have a liver test**	3 years	65,137	103,350	63.0%

ID	Description	Original recommendation	Adapted quality indicator	Lookback period	Numerator *n*	Denominator *n*	Overall rate in EMRALD® %
Domain: Treatment Targets (11 to 16)							
11	Achieving HbA1c targets (7%)	Therapy in most individuals with type 1 or type 2 diabetes should be targeted to achieve an HbA1c ≤ 7.0% in order to reduce the risk of microvascular and, if implemented early in the course of disease, macrovascular complications	% of adults with diabetes who have an HbA1c **whose last measured HbA1c < 7%**	18 months	11,981	20,083	59.7%
12	Achieving HbA1c targets (6.5%)	An HbA1c ≤ 6.5% may be targeted in some patients with type 2 diabetes to further lower the risk of nephropathy and retinopathy, but this must be balanced against the risk of hypoglycemia.	% of adults with diabetes who have an HbA1c **whose last measured HbA1c < 6.5%**	18 months	7,918	20,083	39.4%
13	Antihypertensives for high systolic BP	Antihypertensive therapy should be strongly considered if systolic blood pressure readings average 140 mmHg or higher in the presence of macrovascular target organ damage.	% of adults with CAD or stroke and an average systolic blood pressure ≥ 140mmHg (average of all readings in last 1 year) **who have a prescription for antihypertensive therapy**	18 months	2,473	3,033	81.5%
14	Blood pressure targets for patients with diabetes	Persons with diabetes mellitus should be treated to attain systolic blood pressures of less than 130 mmHg and diastolic blood pressures of less than 80 mmHg.	% of adults with diabetes whose most recent blood pressure < 130/80	1 year	7,489	19,741	37.9%
15	Antihypertensives for patients with high DBP	Antihypertensive therapy should be strongly considered if diastolic blood pressure readings average 90 mmHg or higher in the presence of macrovascular target organ damage or other independent cardiovascular risk factors.	% of adults with CAD or stroke with an average diastolic BP ≥ 90mmHg (over the past 1 year) **who are on antihypertensives**	18 months	401	580	69.1%

ID	Description	Original recommendation	Adapted quality indicator	Lookback period	Numerator *n*	Denominator *n*	Overall rate in EMRALD® %
16	Antihypertensives for elderly patients >80 years	In the very elderly (age 80 years and older), who do not have diabetes or target organ damage, the SBP threshold for initiating drug therapy is ≥ 160 mmHg and the SBP target is < 150 mmHg.	% of adults aged ≥ 80 without diabetes, CAD, CKD or stroke and a most recent systolic BP of ≥ 160mmHg **who are on antihypertensives**	18 months	103	158	65.2%
Domain: Pharmacologic and/or Procedural Therapy (17 to 23)							
17	Anti-platelet agents for patients with CAD	Patients with documented CAD, in the absence of specific contraindications or documented intolerance, should be treated with anti-platelet agents; for patients with a history of chronic stable angina, remote PCI, or CABG, ASA (75 mg PO to 162 mg) PO daily indefinitely	% of adults with CAD who have a prescription for anti-platelet agents	18 months	5,264	2,119	43.4%
18	Statin use among patients with diabetes over the age of 40	Statin therapy should be used to reduce cardiovascular risk in adults with type 1 or type 2 diabetes with any of the following features: • Clinical macrovascular disease; • Age ≥ 40 years • Age <40 years and 1 of the following: diabetes duration >15 years and age >30 years, microvascular complications	% of patients ≥ 40 years with diabetes **who have a prescription for statin**	18 months	12,199	20,760	58.8%
19	ACE or ARB use for patients with diabetes over age 55	ACE inhibitor or ARB, at doses that have demonstrated vascular protection, should be used to reduce cardiovascular risk in adults with type 1 or type 2 diabetes with any of the following: • Clinical macrovascular disease, • Age ≥ 55 years, • Age < 55 years and microvascular complications.	% of adults ≥ 55 years with diabetes who have a prescription for ACE inhibitors or ARBs	18 months	11,704	16,548	64.1%

ID	Description	Original recommendation	Adapted quality indicator	Lookback period	Numerator *n*	Denominator *n*	Overall rate in EMRALD® %
20	Antihypertensive medication	Initial therapy should consist of monotherapy with a thiazide diuretic; a β-blocker (in patients younger than 60 years); an ACE inhibitor (in nonblack patients); a long-acting CCB; or an ARB. If there are adverse effects, another drug from this group should be substituted. Hypokalemia should be avoided in patients treated with thiazide diuretic monotherapy.	% of adults with hypertension **who have prescription for at least one of these kinds of drugs:** thiazide diuretics; Beta-blockers; ACE inhibitors; CCBs or ARBs	18 months	35,858	48,965	73.2%
21	Aggressive antihypertensive medication	Combination therapy using two first-line agents may also be considered as initial treatment of hypertension if systolic blood pressure is 20 mmHg above target or if diastolic blood pressure is 10 mmHg above target.	% of adults with hypertension with a most recent BP higher than the target and **who have a prescription for at least two first-line antihypertensives**	18 months	2,245	5,314	42.2%
22	ACE or ARB for patients with CVD or kidney disease	For persons with cardiovascular or kidney disease, including microalbuminuria or with cardiovascular risk factors in addition to diabetes and hypertension, an ACE inhibitor or an ARB is recommended as initial therapy.	% of adults with CAD, diabetes, hypertension or CKD **who have a prescription for ACE or ARBs**	18 months	34,137	64,989	52.5%
23	ACE or ARB for patients with CAD	An ACE inhibitor or ARB is recommended for most patients with hypertension and CAD	% of patients with hypertension and CAD who have a prescription for ACE inhibitors or ARBs	18 months	5,121	7,063	72.5%

Appendix C Description of Chronic Obstructive Pulmonary Disease Quality Indicators measured in the primary care Electronic Medical Record and their adaptations and limitations

Original quality indicators (Gershon et al 2018)[164]		**Quality indicator adapted to EMR**				**Limitation to measurement in primary care EMR**
Domain	**Quality indicator definition**	**Numerator**	**Denominator**	**Time frame**	**Quality Indicator**	
Influenza vaccination received	Percentage of people with COPD who received an influenza immunization in the preceding flu season	Patients who received the influenza vaccine	Patients with COPD who were not allergic to influenza vaccines	18 months	Percentage of people with COPD who received an influenza vaccination in the last 18 months.	Does not capture flu vaccines that are administered in community pharmacies, walk-in clinics or other settings outside of primary care clinics unless it is manually recorded in the EMR
Pneumococcal vaccination received	Percentage of people with COPD who received pneumococcal vaccination as *per latest guidelines*†.	Patient who received at least one dose of the pneumococcal vaccine	Patients with COPD who were not allergic to pneumococcal vaccines	Any point in time (in the history of the chart)	Percentage of people with COPD who received pneumococcal vaccination in the history of the EMR.	Criteria for recommendation of revaccination after 5 years for 23-valent pneumococcal polysaccharide vaccine (for immunocompromised persons, persons with functional or anatomic asplenia) as per latest guidelines† not considered
Smoking assessment among non-smokers	Percentage of people with COPD who are non-smokers, including former smokers, who were asked about smoking status and secondhand smoke exposure in the last year	Smoking status is recorded in the patients' risk factors	Patients with COPD	Any point in time (in the history of the chart)	Smoking history Percentage of people with COPD who had their smoking status recorded in the EMR.	Secondhand smoke exposure was not recorded in a standard way and poorly documented. This QI was adapted to apply to whether the smoking status was recorded for all patients with COPD to determine the rate of smoking assessment. The timestamps for when changes to smoking status occurred were poorly documented, thus smoking history was not limited to the previous year as per the original QI.

Original quality indicators (Gershon et al 2018)[164]		Quality indicator adapted to EMR				Limitation to measurement in primary care EMR
Domain	**Quality indicator definition**	**Numerator**	**Denominator**	**Time frame**	**Quality Indicator**	
Smoking cessation intervention received	Percentage of people with COPD who are current smokers who received a smoking cessation intervention (e.g. counselling, pharmacotherapy) in the last year	Smoking cessation drugs documented in medication list or smoking cessation/counselling claims (E079, K039, Q042A or other claims labelled 'smoking cessation' or 'smoking consulting') (refer to Appendix E for full list)	Patients with COPD with smoking history recorded who are current smokers	Any point in time (in the history of the chart)	Percentage of people with COPD whose last recorded smoking status is 'current smoker' who have a prescription for a smoking cessation drug or a record of smoking cessation counselling at any point in time in the history of the chart	Patient's smoking history may not be up-to-date and may have already quit smoking; patient may be using over-the-counter smoking cessation medication that is not recorded in the medication field; some smoking cessation drugs which are used for other purposes, such as bupropion used as anti-depression medication were not included
Spirometry to confirm diagnosis	Percentage of people with COPD who had their diagnosis confirmed by post bronchodilator spirometry	Patients who had pulmonary function tests recorded in their laboratory results	Patients with COPD	Any point in time (in the history of the chart)	Percentage of people with COPD who have a record of a pulmonary function test at in the history of their electronic medical record.	PFTs done prior to the patient records being electronized may be missing from the chart, as well as PFTs ordered by a different physician at a different clinic and not retroactively recorded. The PFT results were not standardized. The date of diagnosis of COPD was not documented and it was there was poor specification of if the PFTs were post-bronchodilator measurements.

Original quality indicators (Gershon et al 2018)[164]		Quality indicator adapted to EMR				Limitation to measurement in primary care EMR
Domain	**Quality indicator definition**	**Numerator**	**Denominator**	**Time frame**	**Quality Indicator**	
Long-acting bronchodilators	Percentage of people with moderate to very severe COPD who were prescribed a long-acting beta-agonist or long-acting anticholinergic	Long-acting bronchodilators in medication list (long-acting beta-agonist or long-acting anticholinergic)	Patients with COPD	Any point in time (in the history of the chart)	Percentage of people with COPD (all levels of severity) who have a prescription for a long-acting beta-agonist or long-acting anticholinergic.	Medications prescribed by other providers (e.g. specialists) that are not recorded in the primary care EMR will be missing. No validated measure of COPD severity, therefore the denominator included all stages of COPD.
Short-acting anticholinergic bronchodilators	Percentage of people with symptomatic COPD who were prescribed a short-acting beta-agonist or short-acting anticholinergic bronchodilator	Short-acting anticholinergic bronchodilators in medication list (short-acting beta-agonist or short-acting anticholinergic)	Patients with COPD	Any point in time (in the history of the chart)	Percentage of people with COPD who have a prescription for a short-acting beta-agonist or short-acting anticholinergic bronchodilator	Medications prescribed by other providers (e.g. specialists) that are not recorded in the primary care EMR will be missing. No validated measure of COPD severity, therefore the denominator included all stages of COPD.
Combination inhaled corticosteroids and long-acting bronchodilators	Percentage of people with moderate to very severe COPD who had two or more exacerbations in the previous year who were prescribed inhaled corticosteroids with long-acting bronchodilators	Combination inhaled corticosteroids and long-acting bronchodilators in medication list (combination inhaler; or long-acting bronchodilators and a corticosteroid separately)	Patients with COPD	Any point in time (in the history of the chart)	Percentage of people with COPD who have a prescription for combination inhaled corticosteroid and long-acting bronchodilator (combination inhaler; or long-acting bronchodilators	Medications prescribed by other providers (e.g. specialists) that are not recorded in the primary care EMR will be missing. No validated measure of COPD severity, therefore the denominator included all stages of COPD.

Original quality indicators (Gershon et al 2018)[164]		Quality indicator adapted to EMR				Limitation to measurement in primary care EMR
Domain	**Quality indicator definition**	**Numerator**	**Denominator**	**Time frame**	**Quality Indicator**	
					and a corticosteroid)	
Opioids	Percentage of people with very severe COPD and intractable dyspnea who were prescribed an opioid	Opioids prescribed (ever)	Patients with COPD	Any point in time (in the history of the chart)	Percentage of people with COPD who have a prescription for an opioid	No validated measure of COPD severity or intractable dyspnea, therefore the denominator included all stages of COPD.
Long term oxygen therapy (LTOT) assessment	Percentage of people with severe COPD and/or an oxygen saturation less than or equal to 88% when stable who are assessed for LTOT	Oxygen therapy is in CPP and treatments	Patients with COPD	Any point in time (in the history of the chart)	Percentage of people with COPD who have a record of oxygen therapy at any point in their electronic medical charts	No validated measure of COPD severity or arterial oxygen saturation levels, therefore the denominator included all stages of COPD.
Pulmonary rehabilitation referral	Percentage of eligible people with moderate to severe COPD who have ever been referred to a multidisciplinary pulmonary rehabilitation program meeting current standardized guidelines	Evidence of Pulmonary Rehabilitation in consultation letters or in the patient cumulative patient profile	Patients with COPD	Any point in time (in the history of the chart)	Percentage of people with COPD who have a record of pulmonary rehabilitation at any point in their electronic medical charts	No validated measure of COPD severity, therefore the denominator included all stages of COPD. Pulmonary rehabilitation referrals made in a letter on paper and not documented in the EMR. False positive results are possible if the search terms were part of a pre-formatted ‘stamp’ used in the consult notes but not actual referrals for the patient.

Appendix D Description of Chronic Obstructive Pulmonary Disease Quality Indicators not measured in the primary care Electronic Medical Record (EMR) and their limitations

Original quality indicator (Gershon et al. 2018)[164]		**Limitation to measurement in primary care EMR**
Domain	**Quality indicator definition**	
Individualized comprehensive management plan	Percentage of people with COPD who had a current individualized comprehensive management plan relevant to their stage of disease based on annual clinical and psychosocial assessment	Documentation of COPD management plans are not documented in a consistent or standardized format in the primary care EMR.
Recurrent Hospitalization	Percentage of people with COPD with two or more COPD-related hospitalizations in the past year	Hospitalization records are not well documented in the primary care EMR.[96]
Advance care directives	Percentage of people with advanced COPD who discussed and had documented health care directives (or advanced directives) and goals of care with their health care professional	Documentation of advance care directives not recorded in a consistent or structured format in the primary care.
Palliative care	Percentage of people with advanced COPD, who received palliative care that addressed their physical, social and emotional needs	Palliative care receipt is not documented in a consistent or structured format in the primary care EMR.
Influenza vaccination offered	Percentage of people with COPD who were offered an influenza immunization in the preceding flu season	Whether or not the influenza vaccine was 'offered' (but not administered or refused by the patient) was not consistently documented in the primary care EMR.
Smoking cessation success	Percentage of people with COPD who had smoked and who quit smoking for at least one month	Timestamps for when the patient had begun smoking or quit smoking were not consistently documented in the primary care EMR. Only the last available smoking status data was analyzed at the time of data collection
Spirometry for case finding	Percent of people presenting with noncardiac exertional dyspnea, chronic cough (≥6 months) wheeze or two or more episodes per year of bronchitis and/or COPD risk factors who received spirometry.	Currently no validated way of identifying non-cardiac exertional dyspnea, chronic cough of greater than 6 months in the primary care EMR. We measured the rate of spirometry receipt among all patients with COPD in a related QI (spirometry to confirm diagnosis).
Inhaler device training	Percentage of people with COPD given a new inhaler, spacer, or nebulizer who were trained by a qualified health care provider to use the device	Inhaler device training not documented in a consistent or structured format in the primary care EMR.

Original quality indicator (Gershon et al. 2018)[164]		Limitation to measurement in primary care EMR
Domain	**Quality indicator definition**	
Long term oxygen therapy use	Percentage of people with COPD who required oxygen† received long term oxygen therapy in the previous year †PaO2 <=55mmHg or oxygen saturation ≤88%, or PaO2 56-60mmHg with cor pulmonale, pulmonary hypertension, persistent erythrocytosis, exercise limited by hypoxemia or nocturnal hypoxemia	Oxygen saturation levels not well documented in the primary care EMR.
Pulmonary rehabilitation received	Percentage of eligible people with moderate to severe COPD who have ever received a multidisciplinary pulmonary rehabilitation program meeting current standardized guidelines	Multidisciplinary pulmonary rehabilitation receipt not documented in the primary care EMR.
Pulmonary rehabilitation program maintenance	Percentage of eligible people with COPD who have completed a multidisciplinary pulmonary rehabilitation program who are engaged in a maintenance program that includes ongoing exercise education and social support.	Multidisciplinary pulmonary rehabilitation receipt not documented in the primary care EMR.
Pulmonary rehabilitation access	Percentage of eligible people with moderate to severe COPD who have access to a multidisciplinary pulmonary rehabilitation program	Access to pulmonary rehabilitation not documented in the primary care EMR.
Emergency department visits	Percentage of people with COPD seen in the emergency department for COPD exacerbations in the last year	Hospitalization records, including emergency department visits for COPD exacerbations are not well documented in the primary care EMR.
Hospital admissions	Percentage of people with COPD who were hospitalized for one or more COPD exacerbations in the previous year	Hospitalization records, including emergency department visits for COPD exacerbations are not well documented in the primary care EMR.
Hospital follow-up	Percentage of people discharged from hospital or an emergency room following a visit for COPD who were assessed by a healthcare provider in the following 2 weeks	Hospitalization records, including emergency department visits for COPD exacerbations are not well documented in the primary care EMR.
Non-invasive ventilation (NIV) assessment and delivery	Percentage of people admitted to hospital with an exacerbation of COPD and respiratory failure, who were promptly assessed for NIV, and if indicated, for whom subsequent delivery was promptly undertaken	Hospitalization records, including emergency department visits for COPD exacerbations, and receipt of non-invasive ventilation assessment receipt are not well documented in the primary care EMR.

Original quality indicator (Gershon et al. 2018)[164]		Limitation to measurement in primary care EMR
Domain	**Quality indicator definition**	
Pulmonary rehabilitation after acute exacerbation of COPD	Percentage of people hospitalized for a COPD related exacerbation who were considered for pulmonary rehabilitation within 4 weeks of hospital discharge	Hospitalization records, including emergency department visits for COPD exacerbations are not well documented in the primary care EMR.
Hospital care	Percentage of people with COPD admitted to hospital with an exacerbation who were cared for by a respiratory team	Hospitalization records, including emergency department visits for COPD exacerbations are not well documented in the primary care EMR.
Appropriate discharge from hospital	Percentage of people with COPD admitted to hospital with an exacerbation, who received appropriate discharge planning with appropriate discharge support	Hospitalization records, including emergency department visits for COPD exacerbations are not well documented in the primary care EMR.
COPD Action Plan	Percentage of people with COPD and a previous exacerbation or exacerbations who were given individualized written advice on early recognition of future exacerbations and management strategies (including appropriate provision of antibiotics and corticosteroids for self-treatment at home) by a qualified health care professional.	COPD Action Plans and hospitalization records, including emergency department visits for COPD exacerbations are not well documented in the primary care EMR.
Corticosteroids for acute exacerbation	Percentage of people with moderate to severe COPD and a previous exacerbation or exacerbations who received systemic corticosteroids during their last exacerbation	No validated measure of COPD severity. Acute COPD exacerbations not documented in the primary care EMR. Justification for prescribing medications not documented in the primary care EMR.
Antibiotics for acute exacerbation	Percentage of people with a COPD exacerbation, defined by presence of at least two of increased dyspnea, sputum production, or sputum purulence, who received antibiotics during their last exacerbation	No validated measure of COPD severity. Acute COPD exacerbations not documented in the primary care EMR. Justification for prescribing medications not documented in the primary care EMR

Note 1: COPD severity based on GOLD Grades for severity of airflow limitation in COPD patients with FEV1/FVC<0.70:

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

Note 2: A COPD-related hospitalization is defined as a hospitalization where a person's COPD was a contributory cause (e.g. a hospitalization for an acute exacerbation of COPD, pneumonia, acute decompensated heart failure)

Appendix E List of search terms used for chronic obstructive pulmonary disease medication, therapy or counselling

Medication, therapy or counselling	List of search terms
Short-acting beta-agonist	Albuterol Sandoz-salbutamol Airomir Alti-salbutamol Apo-salvent Neo-vent Novo-salmol Salbulin Salbu* Salamol Ventodisk Ventolin Volmax Terbutaline Bricanyl Fenoterol Berotec Pirbuterol Procaterol Pro-air Orciprenaline Alupent
Short-acting anticholinergic bronchodilator	Ipratropium bromide Atrovent (non-nasal) Combivent Albuterol sulfate Sterinebs Ipravent Ipratrovent Ipramol Sabult*-iprat*
Long-acting beta-agonist	Formoterol Salmeterol Indacaterol Symbicort Fenoterol Duovent Advair Zenhale Oxeze Onbreze Serevent Bambuterol Oxeol

Medication, therapy or counselling	List of search terms
Long-acting beta-agonist (continued)	Bambec Oix Perforomist
Long-acting anticholinergic	Tiotropium bromide Spiriva Glycopyrolate Br Seebri Breezhaler Aclidinium Br Tudorza Genuair
Combination inhaled corticosteroid and long-acting bronchodilator	Symbicort (AstraZeneca, Cambridge, UK) Budesonide formoterol Zenhale (Merck, Kenilworth, New Jersey, United States) Fluticasone Fluticasone vilanterol Glycopyrrolate indacaterol Aclidinium formoterol Olodaterol tiotropium Umeclidinium vilanterol Fluticasone salmeterol Budesonide formoterol
Corticosteroid	Beclomethasone Budesonide Ciclesonide Fluticasone Triamcinolone QVAR Pulmicort Alvesco Aristocort
Opioids	Aneleridine Anilridine Leritine Codeine phosphate Morphine Meperidine Oxycodone Codeine sulph* Hydromorphone h* Propoxyphene Dextro propoxyphene Acetaminophen codeine Tylenol w* codeine Tylenol 3 Atasol 15 Leyopharnol Acet acodeine Codei* acet ASA codeine Acet oxyc*

Medication, therapy or counselling	List of search terms
Opioids (continued)	Fentanyl transderm Fentanyl patch Empracet Oxycod acet Endodan Ratio codeine Codeine contin Novo propoxyn Codeine asa Oxyco asa Propoxyn Darvon Dilaudid Levorphanol Levo dromoran Demerol Supeudol (Note: opium, belladonna & opium, methadone were not included)
Oxygen therapy	O2 Home oxygen Portable oxygen VitalAire CPAP
Smoking cessation drugs	Nicotine Habitrol Nic-assist Nicoderm Nicorette Thrive Nicotrol Nicorelief Varenicline Champix
Smoking cessation/counselling claims:	Billing code E079: Initial discussion with the patient regarding smoking cessation Billing code K039: Smoking Cessation Follow-Up Visit Billing code Q042A: Additional incentive payment for physicians who provide a dedicated subsequent counselling session with their enrolled patients who have committed to quit smoking

* signifies wildcard

Appendix F Qualitative study interview guide to study barriers and facilitators for the uptake and use of EMR-based tools

Pre-interview

1. Greetings and introduction
2. Introduce the purpose of the interview
3. Explain the process and ask permission for recording
4. Receive questions and ensure confidentiality
5. Obtain informed consent
6. Collect clinical characteristic information
    - Physician's number of years in practice
    - Clinic name and location
    - Description of the clinic
        - Size of clinic (number of patients)
        - Number of physicians in the team (PT/FT)
        - List any allied health professionals who work with the team
        - Presence of any IT support staff
    - Number of years using EMR
    - Number of years practicing at the clinic

Interview Objectives

1. Gauge the level of advanced EMR use by the participant - determine if the participant is using EMR custom forms or decision support tools.
2. Did they use the tool? Did they get training and access to installing and using the tools? (Participation on webinar and videos from the research team)
3. Determine the physician's understanding of the EMR tools being studied. *[Coherence]*
4. Determine their perspectives on desires or need for EMR tools for CKD quality improvement. *[Cognitive Participation]*
5. Do they find the tools helpful? (If they haven't used the tools yet, would they find the tools helpful? What would make it helpful?)
6. How often do they use the tools? (How often do they use other advanced EMR tools?)
7. What was preventing them from installing and using the tools?
    - Are they too busy?
    - Are they interested in quality improvement?
    - Are they familiar with advanced tools in their EMR?

- Is their organization/clinic supportive of QI initiatives and/or advanced EMR use? *[Collective Action]*

8. What is their impression of the EMR tools for quality improvement?

Questions

1. Are you currently using decision support tools or custom forms in the EMR as a normal part of your work?
    a. NO: probe follow-up question to assess why they do not use them, and move to the next question
    b. YES: which ones and move on to the next question
2. Do you know about the CKD tools?
    a. NO: (Show the screenshots, videos, or webinar materials) Do you think that such tools could be helpful in your work? Go to **Stream B**
    b. YES: What is the intention of the tool as you understand it? Go to Question 3
3. Have you used the CKD tools?
    a. YES: move on to the **Stream A**
    b. NO: move on to the **Stream B**

Stream A: Question bank for the physicians who have used the CKD tool

Coherence

1. Can you describe your experience with the CKD tool?
    a. Which tool have you used and for which of your patients?
2. Has sufficient training been provided to you to install or use the tool?
3. Do you see quality improvement as necessary for your CKD patients?
4. Do you feel that this CKD tool should be used in your work?

Cognitive Participation

5. How does CKD tool incorporate into your usual ways of working?
6. Do you see the benefits of the tool for your work? If so, how does it benefit your work?
7. What are the effects of using the tool in your practice? How does the tool affect the nature of your own work?
    a. How effective and useful is the tool?
    b. Is the tool helpful for managing/documenting the treatment of your patients?
    c. Does the tool detract you from your patient during the visit?

Collective Action

8. Have you ever spoken about this tool with other members of your team, are they supportive of using the tool?
9. What was your role in implementation of the tool at your clinic? Are there key people who drive implementation of the tool?
10. Is the use of EMR and the CKD tool adequately supported by your clinic?
    a. Is the EMR and the CKD tool supported by existing policies, management, and staff at your clinic? Are there any resources to support the use of EMR and the CKD tool? Is any supervision available for this type of work with advanced EMR use?

Reflexive Monitoring

11. Do you use the tool to get feedback or improve your practice?
    a. Have you modified your practice in response feedback from the tool?
12. Do you have any feedback or other comments about the tool? Are there any changes you would like to see?

Stream B: Question bank for the physicians who have NOT used the CKD tool

Coherence

1. Why have you not used the CKD tools? What has hindered you from installing or using the tools in your EMR?
2. Do you use any advanced functions on the EMR including other tools or custom forms?
3. What do you use to hand out information to patients with CKD or AFib?

Cognitive Participation

4. Do you see quality improvement initiatives as important for CKD patients?
5. Do you think CKD tool can be useful for quality improvement?
6. Do you find any design or technical concerns with these tools? (Show examples of tool function)

Collective Action

7. Could this work well within your current workflow, or would it disrupt your current work?
8. Do you remember being offered training or help to install and use the CKD tool?
    a. Did you watch the walkthroughs, videos, and tutorials?
9. Would further training help you to use CKD tool?
10. Do you find that using custom forms or EMR tools affects your work load, instead of reducing or helping your work?
11. Do you find that there are any difficulties or lack of time to use such EMR tools like the CKD tools?
12. Do you find that there is adequate and ongoing IT support for EMRs from your clinic and staff?
13. How does your team go about introducing QI initiatives at your clinic, and are any of them related to EMR use? Are there guidelines or policies that support the EMR/quality improvement initiatives?

Reflexive Monitoring

14. Do you have any feedback or other comments about the tool? Are there any changes you would like to see?

Appendix G Interview support material and screenshots of chronic kidney disease EMR tools

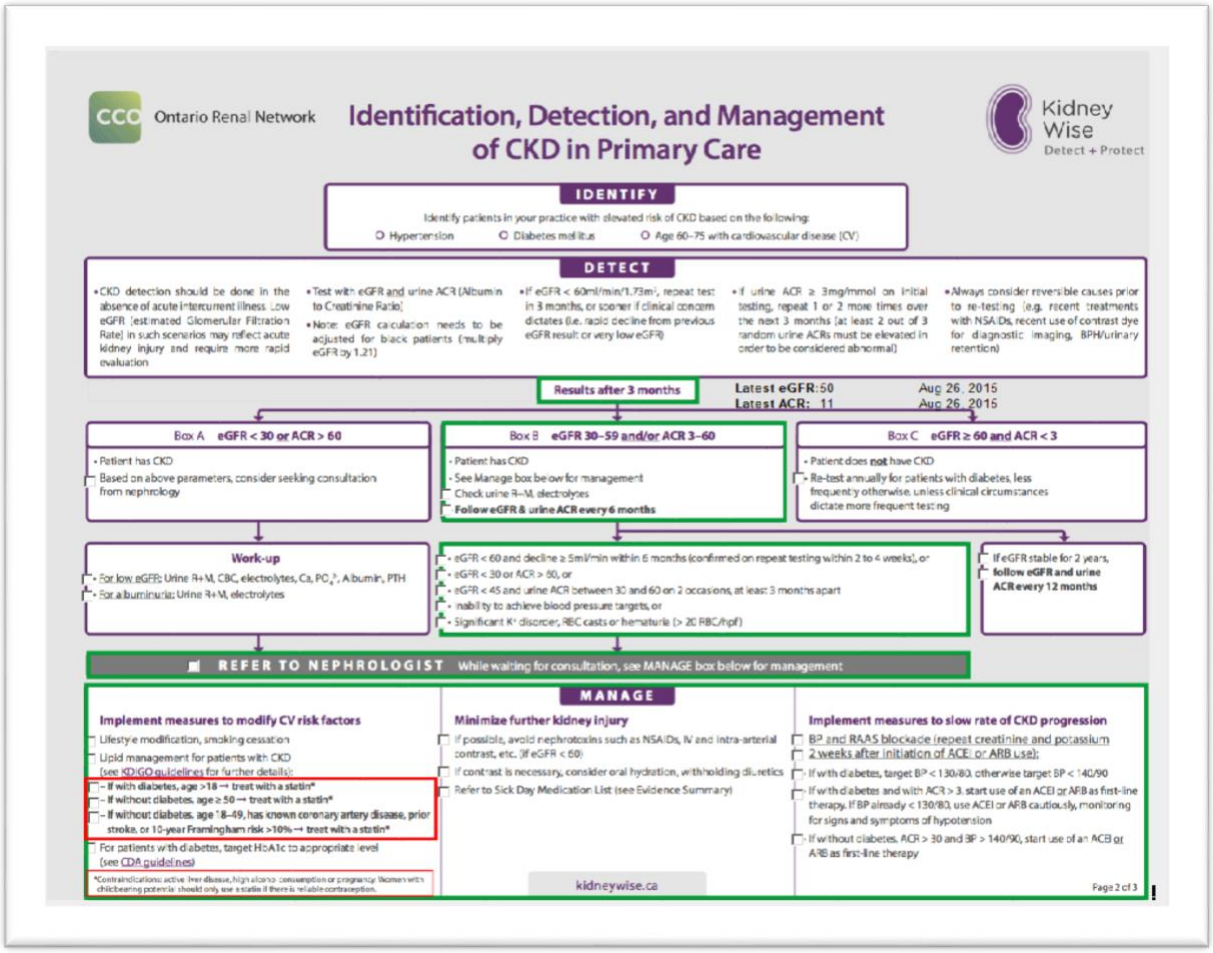
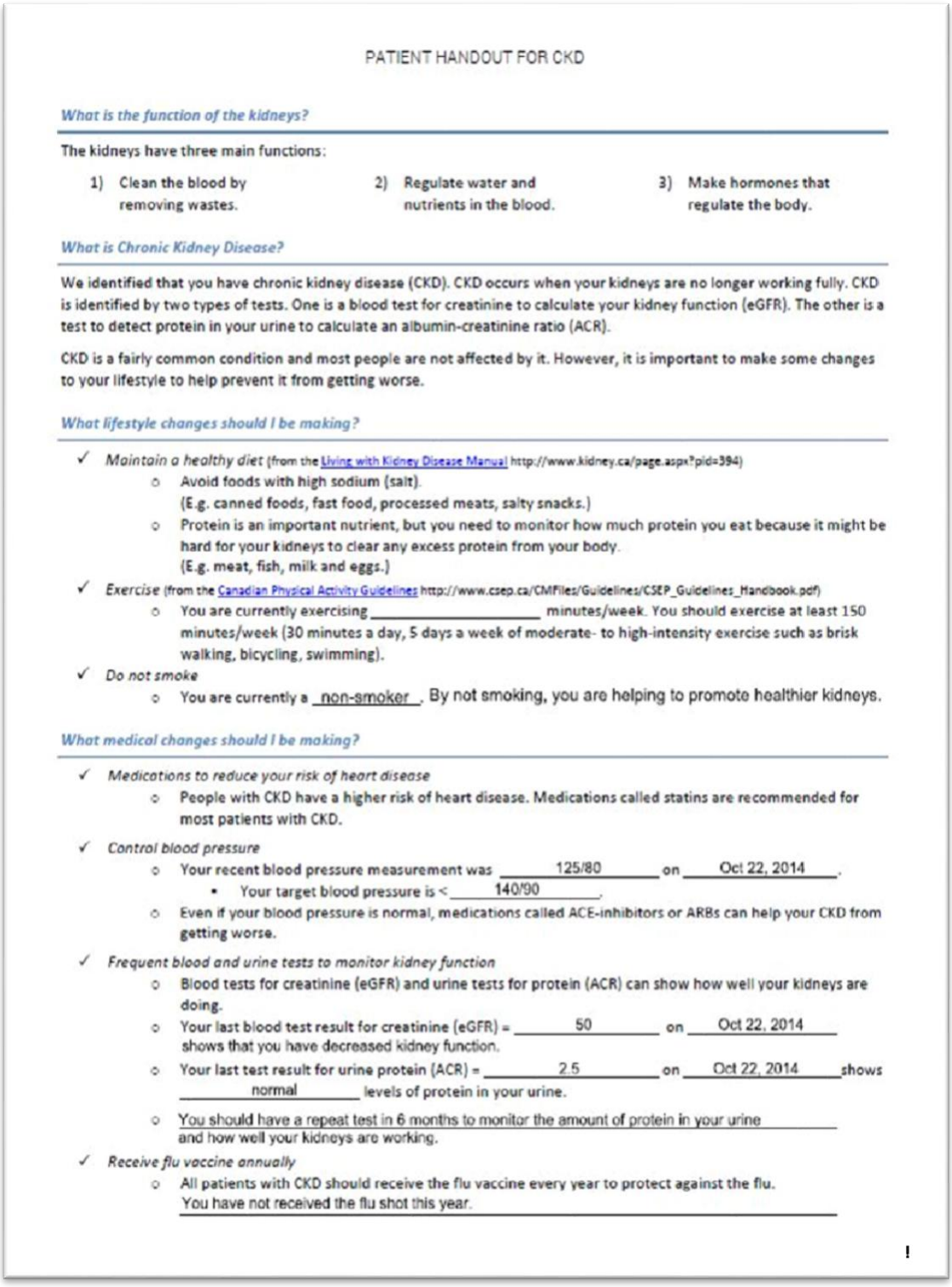


Figure G-1 Screenshot of electronic medical record tools for chronic kidney disease: custom form for recommended identification, detection, and management of chronic kidney disease in primary care based on the Ontario Renal Network's KidneyWise Algorithm



PATIENT HANDOUT FOR CKD

What is the function of the kidneys?

The kidneys have three main functions:

1) Clean the blood by removing wastes.
2) Regulate water and nutrients in the blood.
3) Make hormones that regulate the body.

What is Chronic Kidney Disease?

We identified that you have chronic kidney disease (CKD). CKD occurs when your kidneys are no longer working fully. CKD is identified by two types of tests. One is a blood test for creatinine to calculate your kidney function (eGFR). The other is a test to detect protein in your urine to calculate an albumin-creatinine ratio (ACR).

CKD is a fairly common condition and most people are not affected by it. However, it is important to make some changes to your lifestyle to help prevent it from getting worse.

What lifestyle changes should I be making?

- ✓ *Maintain a healthy diet* (from the Living with Kidney Disease Manual http://www.kidney.ca/page.aspx?pid=394)
  - Avoid foods with high sodium (salt).
    (E.g. canned foods, fast food, processed meats, salty snacks.)
  - Protein is an important nutrient, but you need to monitor how much protein you eat because it might be hard for your kidneys to clear any excess protein from your body.
    (E.g. meat, fish, milk and eggs.)
- ✓ *Exercise* (from the Canadian Physical Activity Guidelines http://www.csep.ca/CMFiles/Guidelines/CSEP_Guidelines_Handbook.pdf)
  - You are currently exercising _____ minutes/week. You should exercise at least 150 minutes/week (30 minutes a day, 5 days a week of moderate- to high-intensity exercise such as brisk walking, bicycling, swimming).
- ✓ *Do not smoke*
  - You are currently a non-smoker. By not smoking, you are helping to promote healthier kidneys.

What medical changes should I be making?

- ✓ *Medications to reduce your risk of heart disease*
  - People with CKD have a higher risk of heart disease. Medications called statins are recommended for most patients with CKD.
- ✓ *Control blood pressure*
  - Your recent blood pressure measurement was 125/80 on Oct 22, 2014.
    - Your target blood pressure is < 140/90.
  - Even if your blood pressure is normal, medications called ACE-inhibitors or ARBs can help your CKD from getting worse.
- ✓ *Frequent blood and urine tests to monitor kidney function*
  - Blood tests for creatinine (eGFR) and urine tests for protein (ACR) can show how well your kidneys are doing.
  - Your last blood test result for creatinine (eGFR) = 50 on Oct 22, 2014 shows that you have decreased kidney function.
  - Your last test result for urine protein (ACR) = 2.5 on Oct 22, 2014 shows normal levels of protein in your urine.
  - You should have a repeat test in 6 months to monitor the amount of protein in your urine and how well your kidneys are working.
- ✓ *Receive flu vaccine annually*
  - All patients with CKD should receive the flu vaccine every year to protect against the flu.
    You have not received the flu shot this year.

Figure G-2 Screenshot of electronic medical record tools for chronic kidney disease: personalized educational patient handout with auto-populated fields based on patient records

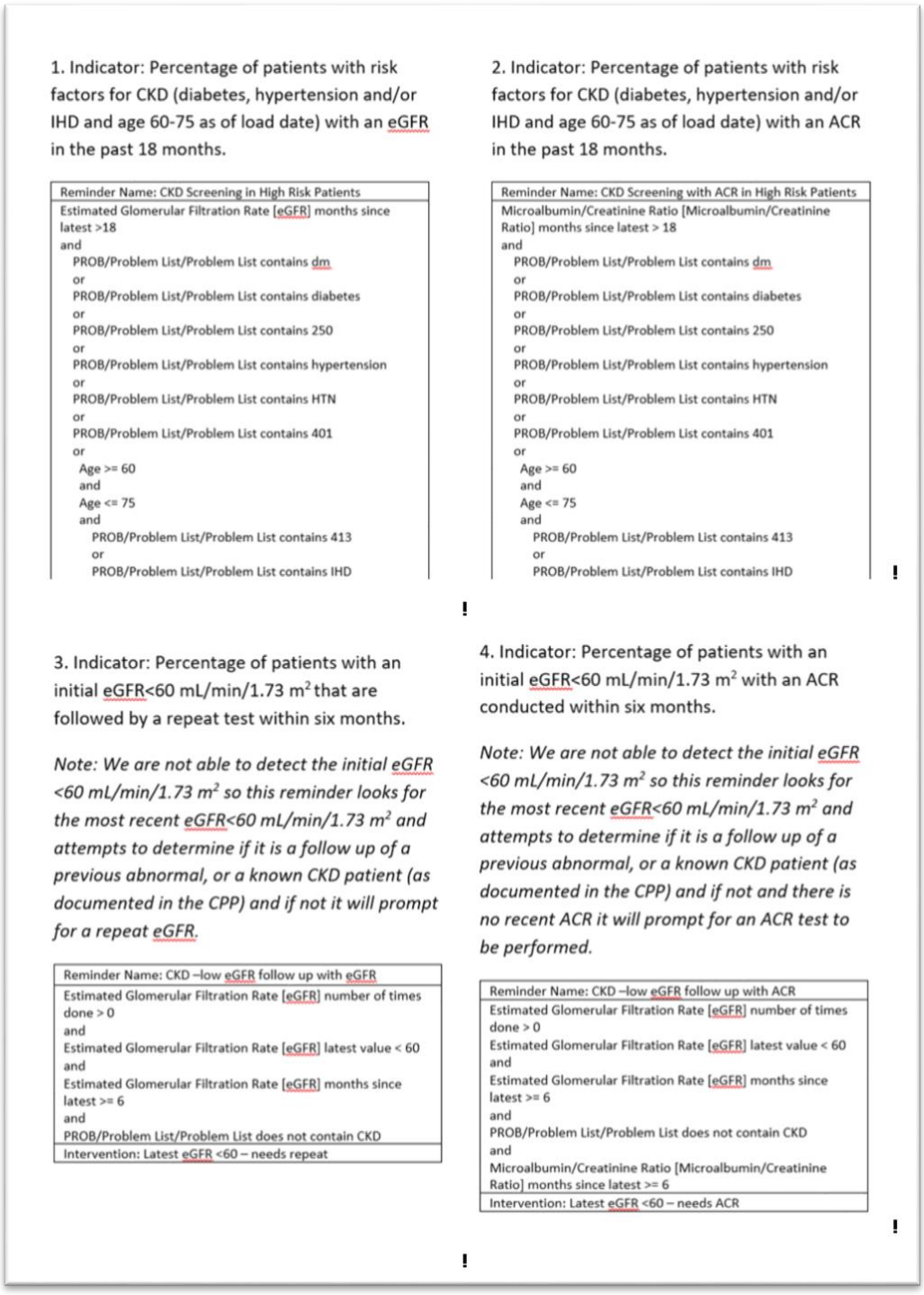
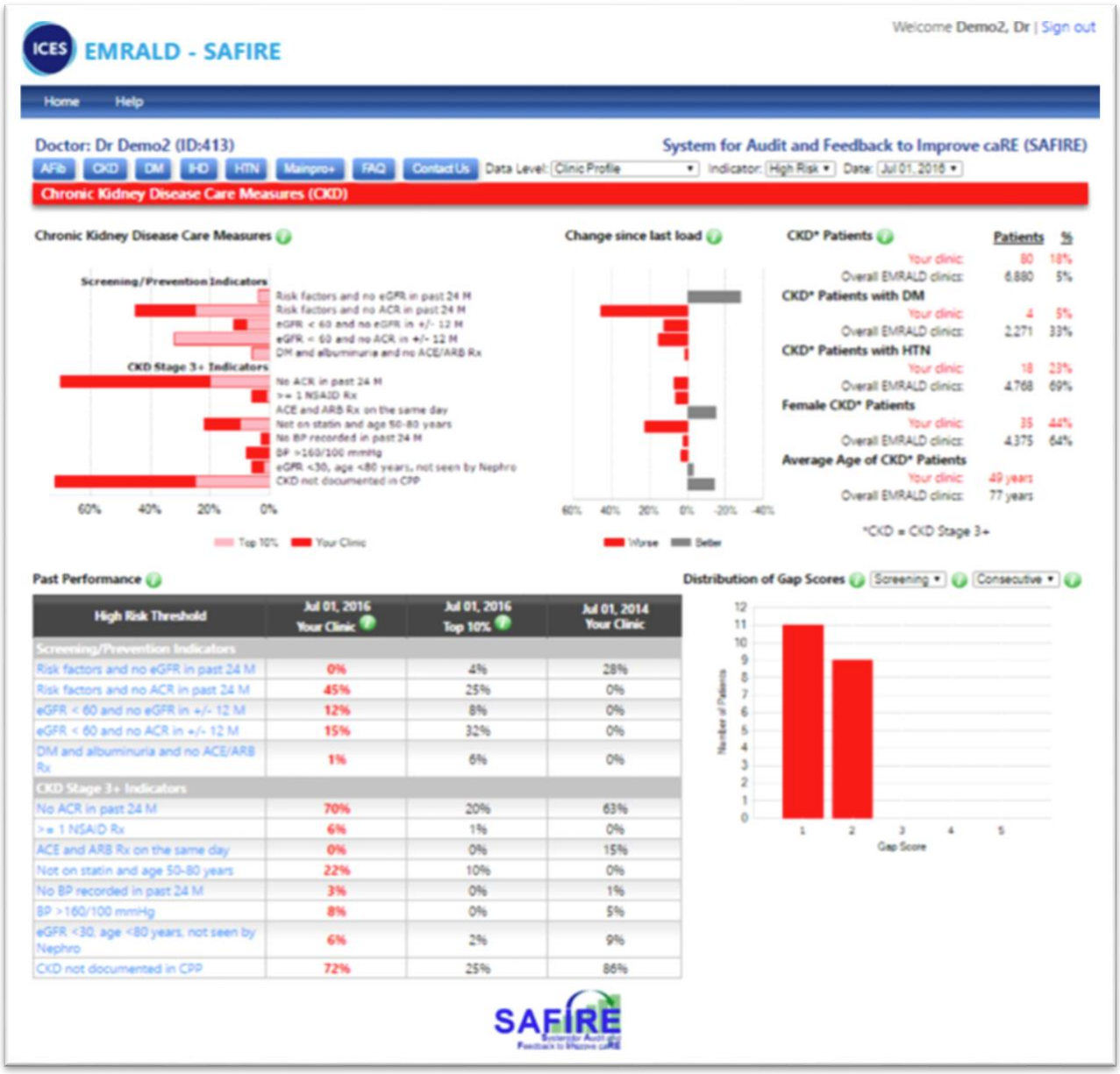


Figure G-3 Screenshot of examples of electronic medical record tools for chronic kidney disease: custom rules for built-in reminders in PS Suite EMR based on the chronic Kidney disease quality of care indicators

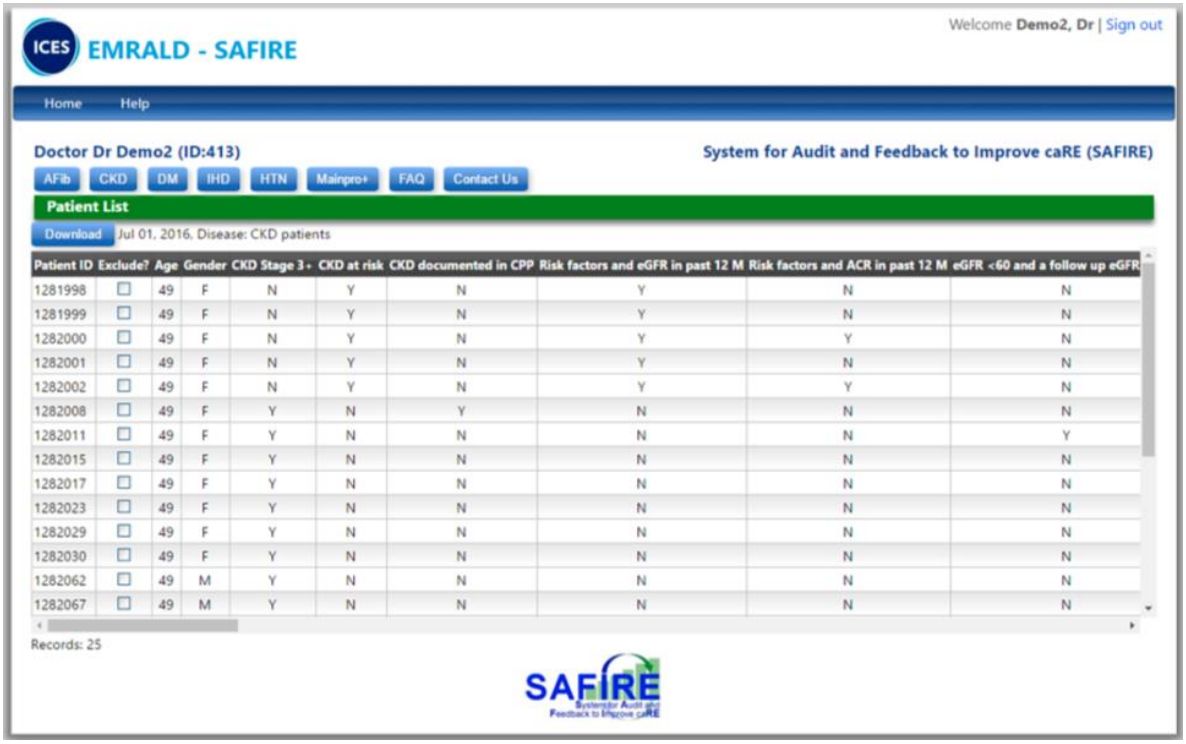
Figure G-4 Screenshot of examples of electronic medical record tools for chronic kidney disease: System for Audit and Feedback to Improve caRE example of chronic kidney disease performance report at the practice level - At target



High Risk Threshold	Jul 01, 2016 Your Clinic	Jul 01, 2016 Top 10%	Jul 01, 2014 Your Clinic
Screening/Prevention Indicators			
Risk factors and no eGFR in past 24 M	0%	4%	28%
Risk factors and no ACR in past 24 M	45%	25%	0%
eGFR < 60 and no eGFR in +/- 12 M	12%	8%	0%
eGFR < 60 and no ACR in +/- 12 M	15%	32%	0%
DM and albuminuria and no ACE/ARB Rx	1%	6%	0%
CKD Stage 3+ Indicators			
No ACR in past 24 M	70%	20%	63%
>= 1 NSAID Rx	6%	1%	0%
ACE and ARB Rx on the same day	0%	0%	15%
Not on statin and age 50-80 years	22%	10%	0%
No BP recorded in past 24 M	3%	0%	1%
BP >160/100 mmHg	8%	0%	5%
eGFR <30, age <80 years, not seen by Nephro	6%	2%	9%
CKD not documented in CPP	72%	25%	86%

Figure G-5 Screenshot of examples of electronic medical record tools for chronic kidney disease: System for Audit and Feedback to Improve caRE example of chronic kidney disease performance report at the practice level - High risk

Figure G-6 Screenshot of examples of electronic medical record tools for chronic kidney disease: System for Audit and Feedback to Improve caRE example of chronic kidney disease performance report at the practice level - Peer comparison



Patient ID	Exclude?	Age	Gender	CKD Stage 3+	CKD at risk	CKD documented in CPP	Risk factors and eGFR in past 12 M	Risk factors and ACR in past 12 M	eGFR <60 and a follow up eGFR
1281998	☐	49	F	N	Y	N	Y	N	N
1281999	☐	49	F	N	Y	N	Y	N	N
1282000	☐	49	F	N	Y	N	Y	Y	N
1282001	☐	49	F	N	Y	N	Y	N	N
1282002	☐	49	F	N	Y	N	Y	Y	N
1282008	☐	49	F	Y	N	Y	N	N	N
1282011	☐	49	F	Y	N	N	N	N	Y
1282015	☐	49	F	Y	N	N	N	N	N
1282017	☐	49	F	Y	N	N	N	N	N
1282023	☐	49	F	Y	N	N	N	N	N
1282029	☐	49	F	Y	N	N	N	N	N
1282030	☐	49	F	Y	N	N	N	N	N
1282062	☐	49	M	Y	N	N	N	N	N
1282067	☐	49	M	Y	N	N	N	N	N

Figure G-7 Screenshot of examples of electronic medical record tools for chronic kidney disease: System for Audit and Feedback to Improve caRE example of chronic kidney disease performance report at the practice level - patient specific feedback for chronic kidney disease

Appendix H Quality of care indicators for patients at risk for chronic kidney disease or with stage 3 or greater chronic kidney disease

At-Target:

- Indicators for patients at risk for CKD
- Percentage of patients with risk factors for CKD and an eGFR in the past *18 months*
- Percentage of patients with risk factors for CKD and an ACR in the *past 18 months*
- Percentage of patients with an eGFR <60 mL/min/1.73 m_2 and another eGFR in ±*6 months*
- Percentage of patients with an eGFR <60 mL/min/1.73 m_2 and an ACR in ±*6 months*
- Percentage of patients with diabetes and albuminuria with a prescription for an ACE inhibitor/ARB

Indicators for patients with stage 3+ CKD

- Percentage of patients with an ACR in the *past 18 months*
- Percentage of patients 50 to 80 years with a prescription for a statin
- Percentage of patients with a BP recorded in the *past 15 months*
- Percentage of patients with at least one BP measure in the *past 15 months* meeting BP targets (<140/90 mm Hg for patients <80 years, <150/90 mm Hg for ≥80 years and <130/80 mm Hg for patients with diabetes)
- Percentage of patients <80 years with an eGFR <30 mL/ min/1.73 m_2 and who have been seen by a nephrologist
- Percentage of patients with CKD documented in the CPP

High-risk:

Indicators for patients at risk for CKD

- Percentage of patients with risk factors for CKD and *no* eGFR in the past *24 months*
- Percentage of patients with risk factors for CKD and *no* ACR in the *past 24 months*
- Percentage of patients with an eGFR <60mL/min/1.73 m_2 and *no* eGFR in ±*12 months*
- Percentage of patients with an eGFR <60 mL/min/1.73 m_2 and *no* ACR in ±*12 months*
- Percentage of patients with diabetes and albuminuria with *no* prescription for an ACE inhibitor/ARB

Indicators for patients with stage 3+ CKD

- Percentage of patients with *no* ACR in the *past 24 months*
- Percentage of patients 50 to 80 years with *no* prescription for a statin
- Percentage of patients with *no* BP recorded in the *past 24 months*
- Percentage of patients with at least one BP measure in the past 15 months with BP >160/100 mm Hg
- Percentage of patients <80 years with an eGFR <30 mL/min/1.73 m_2 and who have *not* been seen by a nephrologist
- Percentage of patients with CKD *not* documented in the CPP
- Percentage of patients with ≥1 prescription for NSAIDs
- Percentage of patients with a prescription for an ACE inhibitor and ARB on the same day

Abbreviations: CKD = chronic kidney disease; eGFR = estimated glomerular filtration rate; ACR = albumin to creatinine ratio; ACE = angiotensin-converting enzyme; ARB = angiotensin receptor blocker; BP = blood pressure; CPP = cumulative patient profile; NSAID = nonsteroidal anti-inflammatory drug.