The Cardiovascular Health in Ambulatory Care Research Team (CANHEART)

Using Big Data to Measure and Improve Cardiovascular Health and Healthcare Services

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Background—The Cardiovascular Health in Ambulatory care Research Team (CANHEART) is conducting a unique, population-based observational research initiative aimed at measuring and improving cardiovascular health and the quality of ambulatory cardiovascular care provided in Ontario, Canada. A particular focus will be on identifying opportunities to improve the primary and secondary prevention of cardiovascular events in Ontario’s diverse multiethnic population.

Methods and Results—A population-based cohort comprising 9.8 million Ontario adults ≥20 years in 2008 was assembled by linking multiple electronic survey, health administrative, clinical, laboratory, drug, and electronic medical record databases using encoded personal identifiers. The cohort includes ≥9.4 million primary prevention patients and ≥400000 secondary prevention patients. Follow-up on clinical events is achieved through record linkage to comprehensive hospitalization, emergency department, and vital statistics administrative databases. Profiles of cardiovascular health and preventive care will be developed at the health region level, and the cohort will be used to study the causes of regional variation in the incidence of major cardiovascular events and other important research questions.

Conclusions—Linkage of multiple databases will enable the CANHEART study cohort to serve as a powerful big data resource for scientific research aimed at improving cardiovascular health and health services delivery. Study findings will be shared with clinicians, policy makers, and the public to facilitate population health interventions and quality improvement initiatives. (Circ Cardiovasc Qual Outcomes. 2015;8:204-212. DOI: 10.1161/CIRCOUTCOMES.114.001416.)

Key Words: ambulatory care ◼ cardiovascular diseases

The Cardiovascular Health in Ambulatory care Research Team (CANHEART) was formed in 2012 to measure and improve the cardiovascular health and quality of ambulatory cardiovascular care provided to the adult population of Ontario, Canada. With a population of over 13 million, Ontario is Canada’s most populous province and is one of the most ethnically diverse jurisdictions in the world. While previous research has identified traditional risk factors for
cardiovascular disease, relatively little is known about how these risk factors are managed in Canada, owing in part to the challenges associated with measuring healthcare delivery across numerous providers in the ambulatory care setting. Measuring and reducing practice gaps in clinical preventive practices are critical to reducing the overall societal burden of cardiovascular diseases, as well as the high costs of cardiovascular related hospitalizations.

Recent advances in the electronic capture of health-related information in the big data era make it now possible to gain new insights into ambulatory care delivery via linkage of multiple population-based health databases in Ontario. Several of these databases contain information that historically involved manual data collection, but is now captured automatically in various electronic databases as part of routine health system administration, clinical care, and behavioral surveillance activities. For example, many important aspects of healthcare delivery in ambulatory care and hospital settings are captured in separate administrative databases, while information on behavioral determinants of health (eg, smoking, physical activity) is captured in large population-based community health surveys. In this article, we describe the methods and data sources used to create a CANHEART cohort of the adult population of Ontario by linking various data sets at the individual level using unique, encoded identifiers and analyzed at the Institute for Clinical Evaluative Sciences (ICES). Linkage and integration of information from multiple databases are required to obtain a comprehensive understanding of healthcare delivery in the ambulatory setting. The CANHEART cohort will be used as a research data platform to address several important research questions, including the following:

1. What are the contributing factors to the large regional and ethnic variations in the incidence rates of major cardiovascular events in Ontario?
2. What are the most important patient, physician, and community characteristics that influence the development of cardiovascular events?
3. How does the Ontario health system perform on various quality indicators related to cardiovascular prevention practices?
4. Will the release of information on variations in cardiovascular health and healthcare delivery result in improvements in cardiovascular outcomes?

Methods

CANHEART is conducting a population-based observational study, based on a cohort of Ontario residents aged 20 to 105 years, constructed through the linkage of multiple population-based health databases available at ICES in Toronto, Ontario, Canada. ICES is Canada’s largest health services research institute, and holds multiple population-based health databases of the Ontario population. ICES is designated as a prescribed entity under Ontario’s Personal Health Information Protection Act. This allows ICES researchers to link together encoded population-based administrative databases for conducting approved research studies under strict privacy and security policies, procedures, and practices (see Data and Privacy at http://www.ices.on.ca) which are reviewed and approved by the Information and Privacy Commissioner of Ontario. Informed consent from participants in the Canadian Community Health Survey (CCHS) was obtained by Statistics Canada before the data were linked to ICES administrative databases. The CANHEART study was approved by and is conducted under the auspices of the Sunnybrook Health Sciences Center Research Ethics Board.

Record Linkage: Data Sources and Cohort Creation

To date, we have linked 17 different individual-level data sources (Figure 1) to create the CANHEART cohort (Figure 2). A brief description of each database is provided in the Data Supplement.

A central database for identifying members of the cohort is the Ontario Registered Persons Database, a registry of Ontario residents who are registered for Ontario health insurance coverage, maintained by the Ontario Ministry of Health and Long-Term Care. This database is used to determine ongoing eligibility for publicly funded health services in Ontario. Each Ontario resident who meets eligibility and residency requirements is issued a unique health card number that is verified at all healthcare system encounters by providers and captured in health-related administrative databases in Ontario. Stored in encoded form to protect individual privacy, the health card number permits deterministic linkages across ICES databases with high linkage rates. All Ontario residents who leave the province to reside elsewhere are required to notify the Ontario Ministry of Health and Long-Term Care and will be censored at the time of departure from the province during statistical analyses.

We chose January 1, 2008, as the inception date for the CANHEART (2008) cohort described in this article to allow a minimum of 3-year follow-up of clinical events. A CANHEART (2002) cohort has also been created using similar methods with 10 years of follow-up data. Residents of long-term care facilities were excluded from the study, as our focus is on community-dwelling residents. Although this article describes the entire cohort of individuals aged 20 to 105 years, it is anticipated that some CANHEART-related research studies may be more appropriately addressed using a subpopulation of the cohort, such as those ≥40 years or those ≥65 years. The corresponding sample sizes for these scenarios are shown in Figure 2. For this cohort, we have defined primary and secondary prevention patients as those without (primary) or with (secondary) a known history of hospitalization for acute myocardial infarction, stroke, congestive heart failure, or revascularization with percutaneous coronary intervention or coronary artery bypass graft surgery in the preceding 20 years, in accordance with other studies.

Sociodemographic and Ethnicity Data

In addition to identifying eligible Ontario residents for the baseline CANHEART cohort, the Ontario Registered Persons Database was also used to obtain sociodemographic information such as date of birth, sex, and postal code. Through linkage of postal codes to Statistics Canada’s census data, the median neighborhood income of individuals can be estimated (for use as a proxy for socioeconomic status), and other neighborhood community characteristics (eg, rural residence) can be ascertained.

Information regarding racial/ethnic background is an important risk factor in cardiovascular health, but is not collected routinely in the Canadian healthcare system despite immigrants comprising 28% of Ontario’s population and coming from all regions of the world. However, we have determined the most likely ethnic background of the over 1.6 million immigrants arriving in Ontario in 1985 or later through linkage to the Citizenship and Immigration Canada Permanent Resident Database using validated algorithms based on country of birth, mother tongue, and surname. The self-reported ethnic background of a large sample of Ontario residents in the general population has also been obtained through linkages to the CCHS described in the following section.

Cardiac Risk Factors and Chronic Diseases

Information about smoking and other relevant health behaviors (eg, physical activity and consumption of fruits and vegetables) has been obtained by linking data from the CCHS to the administrative databases included in the CANHEART cohort database. Initiated in 2001, the CCHS is a population-based survey of a representative sample of 40,000 Ontario residents in each biennial cycle, conducted as part...
**Figure 1.** Data sources linked to create the CARDiovascular HEalth in Ambulatory care Research Team (CANHEART) Cohort. Databases are linked together using unique encoded personal identifiers. *Data are only available for a representative sample of the CANHEART cohort. ASTHMA indicates Ontario Asthma Database; CCHS, Canadian Community Health Survey; CIC, Citizenship and Immigration Canada; CIHI DAD, Canadian Institute for Health Information Discharge Abstract Database; COPD, Ontario Chronic Obstructive Pulmonary Disease Database; EMRALD, Electronic Medical Record Administrative Data Linked Database; GDML, Gamma-Dynacare Medical Laboratories; IPDB, ICES Physician Database; NACRS, National Ambulatory Care Reporting System; OCR, Ontario Cancer Registry; ODB, Ontario Drug Benefit Database; ODD, Ontario Diabetes Database; OHD, Ontario Hypertension Database; OHIP, Ontario Health Insurance Plan Physician Claims Database; ORGD, Office of the Registrar General of Ontario Database; and RPDB, Registered Persons Database.

of an ongoing Statistics Canada computer-assisted (telephone or in-person interview) survey. Data from this survey have been used to create an ideal CANHEART Health Index based on 6 self-reported health behaviors/factors, which will be used for ongoing assessment of the cardiovascular health status of the population. Because important variables such as smoking status are not available for the entire population, we will use multiple imputation methods to impute these variables where required to facilitate statistical analyses.

To identify Ontario residents with hypertension and diabetes mellitus, we used chronic disease algorithms developed in Ontario which have been validated against clinical gold standards, derived from chart reviews. These algorithms are based on physician diagnoses coded in physician claims databases or in hospitalization databases, and allow us to identify nearly everyone who has been diagnosed with these risk factors in the Ontario population.

Chronic disease algorithms based on administrative data do not incorporate measured values regarding disease severity (eg, blood pressure values). To address this limitation, we have linked the CANHEART cohort to the Electronic Medical Record Administrative data Linked Database (EMRALD), an electronic medical record (EMR) database with data from Practice Solutions EMR, the market-leading EMR vendor in Ontario. This database includes blood pressure values recorded as part of routine primary care provided in family physician offices. Blood pressure values are available for over 40,000 CANHEART cohort individuals ≥20 years whose physicians were using an EMR as of January 1, 2008. Previous analyses have demonstrated that EMRALD patients are fairly representative of the overall Ontario population with the exception of younger adults who are less likely to visit a family doctor. The sample of patients with EMR data that can be linked to the CANHEART cohort is expected to rise over time as adoption of EMR systems in Ontario increases and as the EMRALD database expands. As of the end of 2014, the EMRALD database contains data on over 350,000 patients from a network of over 350 primary care physicians across Ontario.

To identify individuals with hyperlipidemia and quantify severity in those with diabetes mellitus, we have used a linkable database of cardiovascular related laboratory tests dating back to 2002 provided by Gamma-Dynacare Medical Laboratories, a commercial laboratory that serves approximately one third of the Ontario population. Table SI in the Data Supplement shows that cohort members receiving lipid laboratory tests at Gamma-Dynacare have similar demographic characteristics to the overall Ontario population ≥40 years who have undergone lipid testing. Lipid and diabetes mellitus screening of the general population ≥40 years is recommended in Canadian practice guidelines and is frequently performed as part of routine preventive care in Canada. Routine screening for kidney disease is also frequently performed in the general population although it is not formally recommended in cardiovascular prevention guidelines. We have determined baseline lipid, glucose, and creatinine values in members of the CANHEART cohort based on the most recent tests done prior to January 1, 2008. It is anticipated that by 2016, the CANHEART cohort will include test results from all major outpatient laboratories in Ontario through linkage to the Ontario Laboratory Information System. Validated administrative database-derived algorithms have also been developed for other chronic diseases such as chronic obstructive
lung disease and asthma, enabling identification of residents with these conditions. To identify those with a history of cancer, linkages were made to the Ontario Cancer Registry, a comprehensive registry of all Ontario residents who have been diagnosed with cancer, excluding nonmelanoma skin cancer. A summary of key chronic disease coding algorithms is shown in Table 1.

Healthcare Utilization
A key focus of the CANHEART initiative is to measure the use of cardiovascular and other healthcare services among Ontario residents. The primary database used to measure the use of ambulatory healthcare services is the Ontario Health Insurance Plan claims database, which contains information on nearly all physician visits, diagnostic tests, and outpatient laboratory services performed in Ontario. The Ontario Health Insurance Plan does not capture privately funded services or services provided by salaried physicians under alternative payment plans such as in Community Health Centers; however, this is estimated to represent a small proportion (<5%) of physician services in Ontario. The Ontario Health Insurance Plan also does not capture private healthcare services purchased by Ontarians in the United States or other provinces, but this is uncommon because residents have access to all physician and hospital services in Ontario with no copayments. Table SII in the Data Supplement provides a list of the Ontario Health Insurance Plan billing codes used to capture healthcare services of

Table 1. Chronic Disease Algorithm Coding Definitions

<table>
<thead>
<tr>
<th>Chronic Disease</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertension9</td>
<td>Either: One hospital admission with a hypertension diagnosis (ICD-9 401x, 402x, 403x, 404x, 405x or ICD-10 I10, I11, I12, I13, I15) or An OHIP claim with a hypertension diagnosis (codes 401, 402, 403, 404, 405) followed within 2 years by either an OHIP claim or a hospital admission with a hypertension diagnosis</td>
</tr>
<tr>
<td>Diabetes mellitus8</td>
<td>Either: One hospital admission with a diabetes mellitus diagnosis (ICD-9 250, or ICD-10 E10, E11, E13, E14) or An OHIP claim (code 250) followed within 2 years by either an OHIP claim or a hospital admission with diabetes mellitus diagnosis Hospital admissions and OHIP claims made between 120 d prior to and 180 d after a gestational record are not counted</td>
</tr>
<tr>
<td>Cancer14</td>
<td>Cancer diagnoses other than nonmelanoma skin cancer (ICD-9 140–208 or ICD-10 C00-C97) identified from either: Hospital discharge and day surgery summaries, or Pathology reports, or Records of patients referred to one of Cancer Care Ontario’s 9 specialized institutions treating cancer patients in Ontario</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease12</td>
<td>Age ≥35 and either: One OHIP claim with a COPD diagnosis (codes 491, 492, 496) or One hospital discharge or day surgery summary with a COPD diagnosis (ICD-9: 491, 492, 496, or ICD-10: J41, J42, J43, J44)</td>
</tr>
<tr>
<td>Asthma13</td>
<td>Either: One hospital admission with an asthma diagnosis (ICD-9: 493, or ICD-10: J45, J46) or Two OHIP claims with an asthma diagnosis (code 493) within 2 years</td>
</tr>
</tbody>
</table>

COPD indicates chronic obstructive pulmonary disease; ICD, International Classification of Diseases; and OHIP, Ontario Health Insurance Plan.
Table 2. Clinical Event Coding Descriptions

<table>
<thead>
<tr>
<th>Clinical Event</th>
<th>ICD-9* (Unless Otherwise Indicated)</th>
<th>ICD-10* (Unless Otherwise Indicated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary events of interest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hospitalization with main diagnosis of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute myocardial infarction20</td>
<td>410</td>
<td>I21, I22</td>
</tr>
<tr>
<td>Stroke21</td>
<td>430, 431, 434, 436, 362.3</td>
<td>I60, I61, I63 (excluding I63.6), I64, H34.1</td>
</tr>
<tr>
<td>Congestive heart failure23</td>
<td>428</td>
<td>I50</td>
</tr>
<tr>
<td>Percutaneous coronary intervention22</td>
<td>CCP codes: 4802, 4803</td>
<td>CCI codes: 1U50, 1U54, 1U57GQ</td>
</tr>
<tr>
<td>Coronary artery bypass graft surgery22</td>
<td>CCP code 481</td>
<td>CCI code 1J76</td>
</tr>
<tr>
<td>Cardiac catheterization</td>
<td>CCP codes: 4892, 4893, 4894, 4895, 4896, 4897, 4898, 4995, 4996, 4997, or OHIP billing codes: Z442 or G297</td>
<td></td>
</tr>
<tr>
<td>Death due to25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ischemic heart disease</td>
<td>410–414</td>
<td>I20-I25</td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
<td>430–438</td>
<td>I60-69</td>
</tr>
<tr>
<td>Major cardiovascular disease</td>
<td>390–434, 436–448</td>
<td>I00-I78</td>
</tr>
<tr>
<td>Emergency department visit with main diagnosis of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>NA</td>
<td>I10, I11, I12, I13 or I15</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>NA</td>
<td>E10, E11, E13 or E14</td>
</tr>
<tr>
<td>Cardiovascular disease</td>
<td>NA</td>
<td>I00-I99</td>
</tr>
<tr>
<td>Secondary events of interest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unstable angina20</td>
<td>411, 413</td>
<td>I20</td>
</tr>
<tr>
<td>STEMI Not coded</td>
<td>Subcode R94.30</td>
<td></td>
</tr>
<tr>
<td>NSTEMI Not coded</td>
<td>Subcode R94.31</td>
<td></td>
</tr>
<tr>
<td>Ischemic stroke</td>
<td>434, 436, 362.3</td>
<td>I63, I64, H34.1 (excluding I63.6)</td>
</tr>
<tr>
<td>Hemorrhagic stroke</td>
<td>430, 431</td>
<td>I60, I61</td>
</tr>
<tr>
<td>Transient ischemic attack</td>
<td>435</td>
<td>G45 (excluding G45.4), H34.0</td>
</tr>
<tr>
<td>Atrial fibrillation24</td>
<td>427.3</td>
<td>I48</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abdominal aortic aneurysm</td>
<td>441.3, 441.4</td>
<td>I71.3, I71.4</td>
</tr>
<tr>
<td>Peripheral artery disease</td>
<td>440.2, 443.9, 444.2</td>
<td>I70.2, I73.9, I74.3, I74.4</td>
</tr>
<tr>
<td>Carotid endarterectomy/stent</td>
<td>5012</td>
<td>UE57, UE50, UE87</td>
</tr>
<tr>
<td>Cancer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lung</td>
<td>162</td>
<td>C33, C34</td>
</tr>
<tr>
<td>Breast</td>
<td>174, 175</td>
<td>C50</td>
</tr>
<tr>
<td>Prostate</td>
<td>185</td>
<td>C61</td>
</tr>
<tr>
<td>Colorectal</td>
<td>153, 154, 159.0</td>
<td>C18, C19, C20, C21, C26.0</td>
</tr>
</tbody>
</table>

CCI indicates Canadian Classification of Health Interventions; CCP, Canadian Classification of Diagnostic, Therapeutic, and Surgical Procedures; ICD, International Classification of Diseases; NA, not applicable; NSTEMI, non–ST-segment–elevation myocardial infarction; OHIP, Ontario Health Insurance Plan; and STEMI, ST-segment–elevation myocardial infarction.

*ICD-9 and CCP coding was used prior to April 2002, and ICD-10 and CCI coding thereafter.

Clinical Events

Data sources for clinical events include the Canadian Institute for Health Information Discharge Abstract Database to identify hospitalizations, the Canadian Institute for Health Information National Ambulatory Care Reporting System database for emergency department visit information, and the Office of the Registrar General of Ontario Database of vital statistics for cause of death data. Prior to 2002, Ontario used diagnostic codes from the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) and thereafter, the Tenth Revision, Canada (ICD-10-CA) for hospitalization and emergency department visit coding.16,17 For Ontario death certificate coding, ICD-9 was used until 2000, and ICD-10 thereafter.16,19 Table 2 provides a validated list of ICD-9 and ICD-10 codes used to identify hospitalizations for acute myocardial infarction, stroke, congestive heart failure, percutaneous coronary

particular interest including primary care and specialist/ cardiologist visits, periodic health exams, and screening for diabetes mellitus, hyperlipidemia, and kidney disease. Codes for cardiac related diagnostic tests such as ECGs, stress tests, echocardiograms, and cardiac catheterizations are also provided. An online data dictionary will be developed on the study Website (http://www.canheart.ca) to show variable definitions and associated data sources used in CANHEART studies.

To study drug utilization, the CANHEART cohort database was linked to the Ontario Drug Benefit Database. The Ontario Drug Benefit plan provides public drug coverage from a comprehensive formulary to all Ontario residents ≥65 years and a subpopulation of low-income Ontarians <65 years who are on social assistance. For those <65 years, we also have drug use information for a subpopulation linked to the EMERALD and CCHS databases.
intervention, and coronary artery bypass graft surgery in Ontario, as well as causes of death, types of emergency department visits, and secondary events. For comparability purposes, the codes used for cardiovascular related groupings of cause of death are consistent with those used by Statistics Canada for routine reporting of cause of death in Canada. Additional validation studies of diagnostic codes for secondary events are planned for the future.

**Physician Characteristics**

CANHEART investigators will study variation in physician practice patterns for cardiovascular related ambulatory care across the province including the characteristics of physicians associated with provision of better preventive care and clinical outcomes. In 2009, there were 25,752 practicing physicians in Ontario including 8,693 primary care physicians and 14,807 specialists (including 595 cardiologists) identified in the ICES Physician Database. This database provides demographic and practice characteristics of all physicians in Ontario such as age, sex, medical school attended, years of practice, and type of practice model. A large majority of Ontario residents are now formally rostered to a primary care physician/practice, allowing us to examine practice profiles of physicians across the province.

**Health Regions**

Ontario has 14 official health regions, known as Local Health Integration Networks (LHINs), further divided into 97 sub-LHINs that are used for planning and administrative purposes. These sub-LHINs have populations ranging from 4468 to 484,497 individuals (Figure 3). Analyses of geographical variations in disease burden will primarily use sub-LHINs as the geographical unit of analysis to facilitate detection of important regional differences which may be obscured at the larger LHIN level. As LHIN- and sub-LHIN-level analyses are routinely used for health system planning and management in Ontario, our geographical results and findings will align with formats commonly used by healthcare managers and decision makers in the province.

**Results**

Baseline characteristics of the CANHEART 2008 cohort are shown in Table 3. Overall, the primary prevention group includes ≈9.4 million individuals (96% of cohort) and the secondary prevention group includes ≈400,000 individuals (4% of cohort). As expected, the secondary prevention group is, on average, older (69 versus 47 years of age) and comprises a greater proportion of males (64% versus 48%) than the primary prevention cohort. Compared with primary prevention patients, a greater proportion of secondary prevention patients are of white ethnicity and are long-term residents of Ontario. Among immigrants arriving in Ontario in 1985 or later, the secondary prevention group has a relatively higher proportion of South Asian and a lower proportion of East Asian immigrants. Secondary prevention patients also have a high prevalence of traditional risk factors with 79% having hypertension and 36% having diabetes mellitus. Lipid levels tend to be lower, however, likely because of statin therapy.

**Discussion**

The CANHEART cohort study has been designed to enable measurement of cardiovascular risk factors and preventive care among the adult Ontario population in all regions of the province. We plan to use the data to measure several important indicators of the cardiovascular health of the population, as well as adherence rates to recommended clinical preventive interventions. We will also study the extent to which variations in patient, physician, and community characteristics contribute to regional variations in the incidence of cardiovascular
Table 3. Characteristics of Cohort (20–105 Year Olds), Continued

<table>
<thead>
<tr>
<th>Population size, n</th>
<th>9397 892</th>
<th>400 581</th>
<th>9798 473</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sociodemographics</strong></td>
<td>null</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td><strong>Primary Prevention</strong></td>
<td>20–29</td>
<td>30–39</td>
<td>40–49</td>
</tr>
<tr>
<td>Population size, n</td>
<td>397</td>
<td>161</td>
<td>478</td>
</tr>
<tr>
<td>Age, y, mean±SD</td>
<td>46.5±16.5</td>
<td>17.8</td>
<td>19.6</td>
</tr>
<tr>
<td>Female</td>
<td>51.9</td>
<td>35.7</td>
<td>51.2</td>
</tr>
<tr>
<td>Income quintile</td>
<td>null</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td>Rural or small-town residence*</td>
<td>11.5</td>
<td>15.6</td>
<td>11.6</td>
</tr>
<tr>
<td><strong>Long-term resident or immigrant &gt;20 y in ON</strong></td>
<td>83.4</td>
<td>94.5</td>
<td>83.8</td>
</tr>
<tr>
<td><strong>Immigrant</strong></td>
<td>null</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td>&lt;10 y in ON</td>
<td>8.5</td>
<td>1.4</td>
<td>8.2</td>
</tr>
<tr>
<td>10–20 y in ON</td>
<td>8.1</td>
<td>4.1</td>
<td>7.9</td>
</tr>
<tr>
<td>Ethnicity (overall)†</td>
<td>null</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td>Black</td>
<td>2.9</td>
<td>1.0</td>
<td>2.8</td>
</tr>
<tr>
<td>East Asian</td>
<td>4.7</td>
<td>1.8</td>
<td>4.6</td>
</tr>
<tr>
<td>Latin American</td>
<td>1.2</td>
<td>0.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Southeast Asian</td>
<td>5.5</td>
<td>4.3</td>
<td>5.4</td>
</tr>
<tr>
<td>West Asian/Arab</td>
<td>2.6</td>
<td>1.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Aboriginal</td>
<td>1.5</td>
<td>0.9</td>
<td>1.4</td>
</tr>
<tr>
<td>White</td>
<td>78.8</td>
<td>87.2</td>
<td>79.2</td>
</tr>
<tr>
<td>Other</td>
<td>1.4</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Ethnicity of recent immigrants (arrival in 1985 or later)</td>
<td>null</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td>Black</td>
<td>10.0</td>
<td>8.1</td>
<td>10.0</td>
</tr>
<tr>
<td>East Asian</td>
<td>18.9</td>
<td>9.8</td>
<td>18.8</td>
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<tr>
<td>Latin American</td>
<td>6.8</td>
<td>6.6</td>
<td>6.8</td>
</tr>
<tr>
<td>South Asian</td>
<td>24.1</td>
<td>33.8</td>
<td>24.3</td>
</tr>
<tr>
<td>Southeast Asian</td>
<td>8.4</td>
<td>7.1</td>
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<td>West Asian/Arab</td>
<td>9.8</td>
<td>10.8</td>
<td>9.8</td>
</tr>
<tr>
<td>White-Eastern European</td>
<td>13.2</td>
<td>14.1</td>
<td>13.2</td>
</tr>
<tr>
<td>White-Western European</td>
<td>7.7</td>
<td>8.7</td>
<td>7.8</td>
</tr>
<tr>
<td>Unable to determine</td>
<td>1.1</td>
<td>0.9</td>
<td>1.1</td>
</tr>
<tr>
<td><strong>Cardiovascular risk factors and comorbidities at baseline (January 1, 2008)</strong></td>
<td>null</td>
<td>null</td>
<td>null</td>
</tr>
<tr>
<td>Current smoker†</td>
<td>21.6</td>
<td>16.4</td>
<td>21.4</td>
</tr>
<tr>
<td>Body mass index, kg/m², mean†</td>
<td>26.0</td>
<td>27.4</td>
<td>26.0</td>
</tr>
</tbody>
</table>

Continued...
The Heart and Stroke Foundation of Canada recently announced 2 mission impact goals: (1) Reduce cardiovascular deaths in Canada by 25%, and (2) reduce the prevalence of cardiovascular risk factors by 10%, both by the year 2020.27 Insights gained from analysis of the linked CANHEART cohort data will be critical to facilitating these goals and other initiatives aimed at reducing the burden of cardiovascular diseases in Canada. Particular strengths of the CANHEART project include the diversity of databases that are linked together (eg, survey, laboratory, drug, hospitalization, and EMR data), the large sample size, the multiethnic population, and the ability to efficiently link these databases and capture all clinical events in a single-payer healthcare system that covers the entire population. Because the study has information obtained from a population-based sample of residents, physicians, and health regions in Ontario, we are able to avoid the problems of selection bias associated with voluntary clinical registries or cohort studies. The resulting research platform could also be used to facilitate low-cost registry-based clinical trials and other interventional studies in the future.28

While we have already assembled and linked many different data sets to establish the feasibility of the CANHEART project, ongoing updates to currently available data sets as well as linkage to new data sets will further enrich the CANHEART cohort and allow us to address some important data and knowledge gaps over time. For example, the utility of cardiovascular imaging screening tests in preventing cardiovascular events remains controversial, and the addition of imaging data will be a future priority.29,30 Additionally, most currently available information focuses primarily on physician services; however, inclusion of information related to primary care services provided by other healthcare professionals such as nurse practitioners and pharmacists is another future objective.

We are planning to enrich the CANHEART initiative via linkages with information about community characteristics that may influence the development of cardiovascular risk factors and events, such as the walkability of neighborhoods and air pollution levels.11,12 In addition, Ontario has several population-based cardiovascular and stroke registries that can be used to further our understanding of cardiovascular events and the transition between hospitals and ambulatory care settings.23,33,34 We also foresee unique opportunities to leverage these data sets to develop novel clinical risk prediction models to help guide clinicians and patients to make optimal healthcare decisions.

Conclusions

The CANHEART research initiative will be a powerful big data resource for scientific research studies aimed at improving cardiovascular health and health service delivery. It represents a major Canadian effort aimed at creating a learning health system whereby data routinely collected from disparate parts of the health system are brought together and analyzed to generate new insights into how to improve patient outcomes.35 The CANHEART investigators are committed to sharing the findings from the initiative with key stakeholders, including clinicians, policy makers, and the public, through a variety of mechanisms including traditional academic publications and presentations as well as new social media methods such as Twitter (@canheart_news) and the study Website (http://www.canheart.ca). We anticipate that the publication of information related to variations in cardiovascular health and health services will stimulate population health interventions and quality improvement initiatives across the province and beyond.

Acknowledgments

We thank all of the data custodians who have provided access to the databases used in the study. In particular, we thank Gamma-Dynacare Medical Laboratories for providing access to the laboratory data being used in the study and Citizenship and Immigration Canada for providing access to the immigration data used in the study.

Sources of Funding

The CANHEART study is funded through a Chronic Diseases Team grant (TCA 118349) from the Institute of Circulatory and Respiratory Health-Canadian Institutes of Health Research (CIHR). Additional project-specific funding has been obtained from the Public Health Agency of Canada (PHAC), a CIHR Operating Grant (MOP-111035), and the Heart and Stroke Foundation. The Institute for Clinical Evaluative Sciences (ICES) 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 article are those of the authors and are independent from the funding sources. No endorsement by ICES, the Ontario MOHLTC, PHAC, or CIHR is intended or should be inferred.

Disclosures

Dr J. Tu is funded by a Tier 1 Canada Research Chair in Health Services Research and a Career Investigator Award from the Heart and Stroke Foundation (HSF). Dr Ko is supported by a Clinician Scientist Award from the HSF, Ontario Provincial Office. Drs Booth, Austin, Kapral, andAlter are supported by Career Investigator Awards from the HSF, Ontario Provincial Office. Dr Booth is also supported by the Department of Medicine at the University of Toronto. Dr Alter is also funded by a Chair in Cardiovascular and Metabolic Rehabilitation, University Health Network-Toronto Rehabilitation Institute, University of Toronto. Dr K. Tu is supported by a Research Scholar Award from the Department of Family and Community Medicine, University of Toronto. Dr Wijeyusundera is supported by a Distinguished Clinician Scientist Award from the HSF of Canada. Dr Atzema is supported by a New Investigator Award from the HSF. Dr Gershon is supported by Clinicians’ Scientists Foundations Washington Farquharson Knowledge Translation Fellowship. Dr Lee is supported by a Clinician-Scientist Award from the Canadian Institutes of Health Research (CIHR). Dr Udell is supported by a Postdoctoral Research Fellowship from the CIHR and Canadian Foundation for Women’s Health. The other authors report no conflicts.

References


The Cardiovascular Health in Ambulatory Care Research Team (CANHEART): Using Big Data to Measure and Improve Cardiovascular Health and Healthcare Services

Circ Cardiovasc Qual Outcomes. 2015;8:204-212; originally published online February 3, 2015; doi: 10.1161/CIRCOUTCOMES.114.001416
Circulation: Cardiovascular Quality and Outcomes is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1941-7705. Online ISSN: 1941-7713

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SUPPLEMENTAL MATERIAL

Supplemental Methods

Description of CANHEART Data Sources

Registered Persons Database (RPDB) – Provides basic demographic information about anyone who has ever received an Ontario health card number. Key data variables include date of birth, date of death, sex, geographical information and time periods for which an individual was eligible for coverage under the Ontario Health Insurance Plan (OHIP). All health card numbers are encoded before being linked to other databases at the Institute for Clinical Evaluative Sciences (ICES).

Canadian Community Health Survey (CCHS) – An ongoing computer-assisted, population-based survey conducted by Statistics Canada since 2000 that uses a multi-stage cluster sampling design to collect information on self-reported health status, health determinants and health care utilization for the Canadian population age 12 and older. The CCHS includes respondents from all ten provinces and three territories in Canada. It is conducted in multiple languages to include non-English and non-French speaking residents, and uses sampling weights in data analyses to be representative of 98% of the Canadian population. For data referred to in this paper, only responses up to 2010 are linkable to other databases because encrypted health card numbers for later respondents were not available at the time of this cohort creation.

Canadian Immigration and Citizenship Permanent Resident (CIC) Database – Contains information from the application records for 2.9 million immigrants who landed in Ontario between 1985 and 2010. Data include permanent residents’ demographic information such as country of birth, mother tongue, landing date, level of education, marital status and immigration category.

Canadian Institute for Health Information Discharge Abstract Database (CIHI DAD) – Comprises individual-level data from the discharge abstracts of Ontario hospitals for acute, chronic and rehabilitative care from 1988 onwards. Information includes admission and discharge dates, diagnoses and complications, procedures and comorbidities. Prior to April 2002, International Classification of Diseases (ICD)-9 coding was used with up to 16 diagnoses recorded in each abstract. Since April 2002, ICD-10 coding has been used with up to 25 diagnoses recorded.

Electronic Medical Record Administrative data Linked Database (EMRALD) – Compilation of clinical information from the electronic medical records (EMR) of patients from family physicians across Ontario. Participation is voluntary, but physicians are required to have been using their EMR system for a minimum of two years to ensure that their records contain near complete information about each patient. Records provide documentation about visits...
including diagnoses, assessments performed and their results, treatment and prescriptions provided and reports received from other health care providers.

**Gamma Dynacare Medical Laboratories (GDML) Database** – Provides outpatient results for select routine laboratory tests, including fasting lipid profiles and fasting glucose tests from 2002 onwards. GDML is a major commercial laboratory provider in Ontario with geographic distribution across Ontario, but a higher concentration in urban areas. Our analyses indicate coverage for the Ontario population for lipid and glucose tests is approximately 25-30%, and that the demographic characteristics of people tested at GDML clinics are similar to those tested elsewhere. Key variables include test performed, service date, specimen collection time and test result.

**ICES Physicians Database (IPDB)** - Comprises yearly information about all physicians in Ontario including demographics, specialties, location or practice, workload and types or services provided. Data come from the OHIP Corporate Provider Database (CPDB), the Ontario Physician Human Resource Data Centre (OPHRDC) database and the OHIP database of physician billings.

**Canadian Institute for Health Information National Ambulatory Care Reporting System (NACRS)** – Provides individual-level data about institution-based ambulatory care, specifically care provided in emergency departments (ED) and out-patient clinics since 2000, and day surgeries since 1988. Data include service dates, service provider, diagnosis and procedure codes; and for ED visits, registration, triage and discharge times and triage level.

**Office of the Registrar General of Ontario Vital Statistics Database (ORGD)** – Contains information about all deaths registered in Ontario since 1990 including cause of death. Since health card numbers are not provided in this dataset, records are linked to the RPDB and other health administrative databases by deterministic (79%) and probabilistic (17%) data linkage.

**Ontario Asthma Database (ASTHMA)** – Validated registry of all Ontarians identified as having asthma since 1991 with demonstrated sensitivity of 84% and specificity of 76% among adults 18 years and older compared with physician-assigned diagnoses identified in chart audits. An individual is said to have asthma if he/she has had two OHIP claims with an asthma diagnosis within two years or one hospitalization with an asthma diagnosis. The registry also includes the date and source of diagnosis using the first record of an asthma diagnosis meeting the above the criteria.

**Ontario Cancer Registry (OCR)** – A registry with information on all Ontarians diagnosed with or who have died from cancer except non-melanoma skin cancer. Cases are identified from hospital discharge and day surgery summaries, pathology reports and patient records at Cancer Care Ontario's specialized institutions which treat cancer patients in Ontario and death certificates.

**Ontario Chronic Obstructive Pulmonary Disease Database (COPD)** – Validated registry of all Ontarians 35 years and older identified as having chronic obstructive pulmonary disease since
1991 with demonstrated sensitivity of 85% and specificity of 78% compared with physician-assigned diagnoses identified in chart audits. An individual is said to have COPD if he/she has had one OHIP claim with a COPD diagnosis or one hospitalization with a COPD diagnosis. The date and source of diagnosis is defined using the first record of a COPD diagnosis meeting the above the criteria.

**Ontario Diabetes Database (ODD)** – Validated registry of all Ontarians identified as having diabetes since 1991 with demonstrated sensitivity of 86% and specificity of 90% compared with physician-assigned diagnoses identified in chart audits. An individual is said to have diabetes if he/she has had two OHIP claims with a diabetes diagnosis, one OHIP service claim for diabetes management or intensive insulin therapy counselling, or one hospitalization with a diabetes diagnosis within two years. The date and source of diagnosis is defined using the first record of a diabetes diagnosis meeting the above the criteria.

**Ontario Drug Benefit Database (ODB)** – Contains information on prescription drug claims covered by and made to the Ontario Drug Benefit programme. This programme primarily covers drug expenses for Ontarians with a valid OHIP card who are 65 years and older or residents of long-term care facilities, but also provides coverage to others such as those receiving social assistance. Key data elements include dispensing date, drug identifier, quantity supplied and whether the recipient is a resident of a long-term care facility.

**Ontario Health Insurance Plan (OHIP) Claims Database** – This database captures all reimbursement claims made since 1991 by registered health care providers who are eligible to claim under OHIP. This includes fee-for-service physicians (covering 94% of Ontario’s physicians), other health care providers and community-based labs. Excluded are services received in psychiatric hospitals, services provided by alternate funding plans (e.g. private insurance and federal programmes), diagnostic procedures performed on an inpatient basis (e.g. radiology, ECGs) and laboratory services performed in hospitals (inpatient or same day). Information includes encrypted service provider and specialty if a physician, diagnosis, service provided, date of service and fee paid.

**Ontario Hypertension Database (OHD)** – Validated registry of all Ontarians identified with hypertension since 1988 with demonstrated sensitivity of 73% and specificity of 95% compared with physician-assigned diagnoses identified in chart audits. An individual is said to have hypertension if he/she has had one hospital admission with a hypertension diagnosis, or an OHIP claim with a hypertension diagnosis followed within two years by either an OHIP claim or a hospital admission with a hypertension diagnosis. The date of the first record of a hypertension diagnosis meeting the above criteria is defined as the date of diagnosis.

**Ontario Visible Minority Database** – Dataset which uses validated lists of South Asian and Chinese surnames to assign an ethnicity of Chinese or South Asian (Canada’s two largest visible minority groups), or “general” to individuals in the RPDB. Surnames not unique to the South Asian or Chinese populations are purposely excluded from the lists. Specificity is over 99.5% and positive predictive value is 89 to 92%; sensitivity is 50% for South Asians, 80% for Chinese.
Table S1 – Characteristics of population with lipid testing at Gamma-Dynacare Medical Laboratories versus elsewhere (40-105 year olds)

<table>
<thead>
<tr>
<th></th>
<th>Tested at GDML</th>
<th>Tested at non-GDML laboratory</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population size, n</td>
<td>1,287,422</td>
<td>3,024,630</td>
<td>4,312,052</td>
</tr>
<tr>
<td><strong>Socio-demographics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, years, mean ± SD</td>
<td>58.4 ± 11.9</td>
<td>57.6 ± 12.2</td>
<td>57.9 ± 12.1</td>
</tr>
<tr>
<td>40-49</td>
<td>27.6</td>
<td>31.4</td>
<td>30.3</td>
</tr>
<tr>
<td>50-59</td>
<td>29.9</td>
<td>28.8</td>
<td>29.1</td>
</tr>
<tr>
<td>60-69</td>
<td>22.7</td>
<td>20.7</td>
<td>21.3</td>
</tr>
<tr>
<td>70-79</td>
<td>14.2</td>
<td>13.2</td>
<td>13.5</td>
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<tr>
<td>80+</td>
<td>5.6</td>
<td>5.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Female</td>
<td>54.6</td>
<td>53.1</td>
<td>53.6</td>
</tr>
<tr>
<td>Low income</td>
<td>36.7</td>
<td>37.5</td>
<td>37.3</td>
</tr>
<tr>
<td>Rural or small town residence</td>
<td>7.8</td>
<td>11.8</td>
<td>10.6</td>
</tr>
</tbody>
</table>

**Cardiovascular disease risk factors and co-morbidities at baseline (January 1, 2008)**

<table>
<thead>
<tr>
<th></th>
<th>Tested at GDML</th>
<th>Tested at non-GDML laboratory</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypertension</td>
<td>45.9</td>
<td>40.2</td>
<td>41.9</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>19.9</td>
<td>15.7</td>
<td>17.0</td>
</tr>
<tr>
<td>Cancer</td>
<td>6.8</td>
<td>6.4</td>
<td>6.5</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease</td>
<td>10.7</td>
<td>10.5</td>
<td>10.6</td>
</tr>
<tr>
<td>Asthma</td>
<td>12.8</td>
<td>10.8</td>
<td>11.4</td>
</tr>
</tbody>
</table>

**Prevalence of cardiovascular disease at baseline (January 1, 2008)**

<table>
<thead>
<tr>
<th></th>
<th>Tested at GDML</th>
<th>Tested at non-GDML laboratory</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute myocardial infarction (AMI)</td>
<td>3.6</td>
<td>3.2</td>
<td>3.3</td>
</tr>
<tr>
<td>Stroke</td>
<td>1.3</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>1.6</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Revascularization*</td>
<td>4.4</td>
<td>3.6</td>
<td>3.8</td>
</tr>
<tr>
<td>AMI/stroke/revascularization*</td>
<td>6.8</td>
<td>6.0</td>
<td>6.2</td>
</tr>
</tbody>
</table>

GDML indicates Gamma-Dynacare Medical Laboratories.

*Revascularization includes percutaneous coronary intervention or coronary artery bypass surgery.
<table>
<thead>
<tr>
<th>Health Service</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodic health exam</td>
<td>OHIP billing code A003 (Gen. Assess. -F.P./G.P.)</td>
</tr>
<tr>
<td>Cholesterol screening</td>
<td>OHIP billing codes claimed on the same day:</td>
</tr>
<tr>
<td></td>
<td>L055 (Lab. Med.-biochem.-cholesterol, total (not with L156 Lab. Med.-biochem.-lipoprotein phenotyping),)</td>
</tr>
<tr>
<td></td>
<td>L117 (Lab. Med.-biochem.-high density lipoprotein cholesterol),</td>
</tr>
<tr>
<td></td>
<td>L243 (Lab. Med.-biochem.-triglycerides not with L156)</td>
</tr>
<tr>
<td>Diabetes screening</td>
<td>OHIP billing codes:</td>
</tr>
<tr>
<td></td>
<td>G498 (D./T. Proc.-endocrinology-intravenous glucose tolerance test),</td>
</tr>
<tr>
<td></td>
<td>L103 (Lab. Med.-biochem.-glucose tolerance test in pregnancy),</td>
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<tr>
<td></td>
<td>L104 (Lab. Med.-biochem.-glucose tolerance test),</td>
</tr>
<tr>
<td></td>
<td>L111 (Lab. Med.-biochem. glucose quantitative (not dipstick)),</td>
</tr>
<tr>
<td></td>
<td>L093 (Lab. Med.-biochem. glycosylated haemoglobin)</td>
</tr>
<tr>
<td>Nephrology screening</td>
<td>OHIP billing code L067 (Lab. Med.-biochem-creatinine (not with L068 Lab. Med.-biochem-creatinine clearance))</td>
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<tr>
<td>Cardiac stress tests</td>
<td>OHIP billing codes:</td>
</tr>
<tr>
<td></td>
<td>G111 (D./T. Proc. cardiovascular dipyridamole thallium stress test tech.),</td>
</tr>
<tr>
<td></td>
<td>G112 (D./T. Proc. cardiovascular dipyridamole thallium stress test prof.),</td>
</tr>
<tr>
<td></td>
<td>G174 (Dobutamine stress test-when rendered out hosp-add),</td>
</tr>
<tr>
<td></td>
<td>G315 (Cardiovascular maximum stress ECG tech. comp.),</td>
</tr>
<tr>
<td></td>
<td>G319 (Cardiovascular maximum stress ECG prof. comp.),</td>
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<tr>
<td></td>
<td>J807 (Nuclear medicine corresponding to J607 (Nuclear medicine myocardial perfusion scan &amp; thallium),</td>
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<tr>
<td></td>
<td>J808 (Nuclear medicine corresponding to J608 (Nuclear medicine delayed thallium myocardial perfusion scan)</td>
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<tr>
<td>ECG</td>
<td>OHIP billing code G313 (D./T. Proc. cardiovascular ECG prof.-G.P.)</td>
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<td>G561 (Echocardiography complete study 1 dimension prof. comp. P1),</td>
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<td>G562 (Echocardiography complete study 1 dimension prof. comp. P2),</td>
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<td></td>
<td>G567 (Echocardiography complete study 2 dimension prof. comp. P1),</td>
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<tr>
<td>Smoking cessation counselling</td>
<td>OHIP billing codes:</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td></td>
<td>E079 (Initial discussion with patient re: smoking cessation)</td>
</tr>
<tr>
<td></td>
<td>K039 (Smoking cessation follow-up visit)</td>
</tr>
<tr>
<td></td>
<td>Q042 (Smoking cessation counselling fee)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Ambulatory care family doctor visits</th>
<th>All non-lab visits with specialist code as ‘00’ and location code ‘office’, ‘home’ or ‘long-term care facility’; Maximum number of family doctor visits per person per doctor per day is one.</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>Ambulatory care specialist visits</th>
<th>All non-lab visits with specialist code not ‘00’, ‘49’, ‘50’ to ‘59’, ‘70’ to ‘81’, ‘90’ or ‘99’, and location code ‘office’, ‘home’ or ‘long-term care facility’; Maximum number of specialty doctor visits per person per doctor per day is one.</th>
</tr>
</thead>
</table>

| Ambulatory care cardiologist visits | ‘All non-lab visits to physicians with main specialty= ”Cardiology” in 2009 IPDB, and location code as ‘O’=office, ‘L’=long-term care or ‘H’=home. Maximum number of cardiologist visits per person per cardiologist per day is one. |

CCI indicates Canadian Classification of Health Interventions; CCP, Canadian Classification of Diagnostic, Therapeutic and Surgical Procedures; ECG, electrocardiogram; OHIP, Ontario Health Insurance Plan.

A complete list of billing codes is available on the Ontario Ministry of Health and Long-Term Care website (Schedule of Benefits for Physician Services under the Health Insurance Act, [http://www.health.gov.on.ca/english/providers/program/ohip/sob/physserv/physserv_mn.html](http://www.health.gov.on.ca/english/providers/program/ohip/sob/physserv/physserv_mn.html)). Accessed May 1, 2014.
Supplemental References


