Prevalence of Cardiovascular Disease in a Population-Based Cohort of High-Cost Healthcare Services Users

Padma Kaul, PhD, Nathan Klassen, MA, Douglas C. Dover, PhD, Nariman Sepehrvand, MD, PhD, Roopinder K. Sandhu, MD, Sean van Diepen, MD, MSc, Kevin Bainey, MD, M. Sean McMurtry, MD, PhD, Robert C. Welsh, MD, Justin A. Ezekowitz, MD, Shaun G. Goodman, MD, Paul W. Armstrong, MD, and Finlay A. McAlister, MD

The Canadian VIGOUR Centre, Department of Medicine, University of Alberta, Edmonton, Alberta, Canada

Original Article

ABSTRACT

Background: Data are limited data on the prevalence of cardiovascular disease (CVD) and multimorbidity in contemporary cohorts of high-cost users (HCUs) in Canada. We examined the following: (i) the prevalence of CVD, with a comparison of total healthcare costs among HCUs with vs without CVD; (ii) the contribution of other comorbidities to costs among HCUs with CVD; and (iii) the trajectory of healthcare costs in the years before and after becoming an HCU.

Methods: The study included adult Alberta patients in the Canadian Institutes of Health Research/Canadian Institute for Health Information Dynamic Cohort of Complex, High System Users from 2011-2012 through 2014-2015. We examined total healthcare costs, including hospital, ambulatory care, physician services, and drugs.

Healthcare expenditures have significantly increased over time in developed countries, including Canada and the US.1,2 A widely recognized fact is that only a small portion of the population accounts for a large portion of health expenditures in these countries. In the US, 5% of the population has been shown consistently to be responsible for > 50% of healthcare costs.3,4 In Canada, estimates indicate that the top 1% and 5% of Ontario’s population account for 34% and 64% of healthcare expenditure, respectively; in British Columbia, the top 5% of healthcare users consumed 30% of physician services spending.5,6 Historically, heart disease has been identified as one of the most costly conditions in the US.7 However, data are limited on the contribution of cardiovascular disease (CVD) in more contemporary cohorts of high-cost users (HCUs) in Canada. The need to fill this important evidence gap is clear, as CVD therapeutics have advanced greatly in the past few decades.

Accordingly, we examined the prevalence of CVD in a cohort of complex HCUs between fiscal years (FYs) 2011-2012 and 2014-2015 in Alberta, Canada and compared health expenditures among HCUs with vs without CVD. In order to provide a more comprehensive estimate of total healthcare costs, we examined not just the hospitalization costs that were used to define the cohort, but also costs of
Results: Among 88,536 HCU, 23.4% had no CVD, 28.9% were hospitalized with a primary diagnosis of CVD, and 47.7% were hospitalized with a secondary diagnosis of CVD. Total healthcare costs were $2.0 billion (20.4% non-hospital costs), $2.8 billion (24.1% non-hospital costs), and $4.9 billion (19.8% non-hospital costs), respectively, in the 3 groups. Many HCU with CVD were frail (74.2%) and many had diabetes (33.8%) or chronic obstructive pulmonary disease (27.9%), which contributed to higher costs and mortality. Healthcare expenditures in HCU with CVD were several times higher than per capita health expenditures in the years prior to, and following, their inclusion in the dynamic HCU cohort.

Conclusions: CVD is very common in HCU of healthcare. HCU with CVD have high rates of frailty and multimorbidity. Further research is needed to identify and intervene earlier, in order to flatten the cost curve in these complex patients.

Methods

Patient population

Alberta patients, aged 18-years and older, in the Canadian Institutes of Health Research (CIHR)/Canadian Institute for Health Information (CIHI) Dynamic Cohort of Complex, High System Users were included in the study. The CIHR/CIHI Dynamic Cohort includes patients whose cumulative acute care (inpatient) costs during a specific fiscal year were in the top 10%. Hospitalization records for FY2011-2012 - FY2014-2015 (ie, April 1, 2011 through March 31, 2015), were stratified by age group (children, adults), province, and FY.

Data

The following data for FY 2009-2010 - FY 2017-2018 were obtained for all Alberta HCU in the dynamic cohort: (i) discharge abstract database (DAD) of all acute care hospitalizations (which includes the primary or most responsible diagnosis and up to 24 secondary diagnoses); (ii) National Ambulatory Care Reporting System (NACRS) of all ambulatory (including emergency department) clinic visits; (iii) practitioner claims for physician cost data; (iv) the Alberta Blue Cross and Pharmaceutical Information Network (PIN) pharmaceutical claims data; and (v) the Alberta Health Care Insurance Plan (AHCIP) registry for demographic data and mortality status.

Costs

The cumulative cost per patient, including inpatient, ambulatory, physician, and drug costs, was estimated for the entire FY in which they were an HCU. The cost of each hospitalization and ambulatory visit was estimated by multiplying the cost of standard hospital stay (CSHS) by its resource intensity weight. The CSHS data for the years of the study are available from the CIHI. Our calculations relied on Alberta’s provincial CSHS using the most recently available case mix grouper (CMG+) for that FY. The PIN data include specifics on all community pharmaceutical dispensing, without restriction by age. Given that the PIN data do not include drug costs, we used the drug cost data included in the Alberta Blue Cross drug database (available primarily for Albertans who are 65 years or older) to obtain the costs. Physician costs were obtained from the practitioner claims data. Most Alberta physicians are remunerated on a fee-for-service basis. Estimates of the value of non—fee-for-service physicians’ clinical services were determined using the assessed value of their “shadow billing” claims. Shadow billing refers to claims that are submitted merely for reporting purposes and compensated through alternate physician payment methods.

Total health expenditures were estimated as the sum of the expenditures identified in inpatient, ambulatory, practitioner claims, and drug prescription fulfillment. The total health expenditure was divided by the total number of patients in each year of the HCU cohort to arrive at the average health expenditure per patient-year.

All costs were adjusted using the consumer price index, to 2018 Canadian dollars, to facilitate comparisons.

Analysis

Patients identified as HCU in each FY of the dynamic cohort were categorized into 3 groups, as follows: (i) patients with no CVD hospitalizations (no CVD); (ii) patients with hospitalizations with CVD as the primary diagnosis (primary CVD); and (iii) patients with hospitalizations with CVD as a secondary diagnosis (secondary CVD). We developed a comprehensive list of International Classification of Diseases, version 10 codes to define CVD (Supplemental Table S1).
Cardiovascular codes relating to pregnancy were excluded from our analysis.

The unit of analysis was person-year, and patients who were HCUs in multiple years were included in the cohorts for each of those years. The demographics, clinical characteristics, and outcomes of patients in the 3 groups, overall and by FY, were examined. Continuous variables are presented as means (± standard deviation) and medians (interquartile range), and categorical variables are presented as frequencies. Comorbidity burden was assessed based on the presence of specific International Classification of Diseases, version 10 codes in any of the patient’s hospitalization records during the year. In addition to individual comorbidities, we calculated the Charlson Comorbidity Index (CCI) and the Hospital Frailty Risk Score (HFRS). The CCI provides a weighted score of a patient’s comorbidity burden based on the number and severity of 19 predefined comorbid conditions; the HFRS weights 109 comorbidities to categorize patients as not-frail (HFRS ≤ 5) or frail (HFRS > 5). The CCI was computed based on comorbidities recorded in any hospitalization during the FY in which the patient was an HCU. The HFRS was calculated based on hospitalizations during the FY in which the patient was an HCU, as well as in the previous year. The ministry of health (Alberta Health) postal code translation file was used to categorize the patient as being either urban/metropolitan or rural.

The incremental impact of the presence of other comorbidities in conjunction with CVD in HCUs was examined by comparing the average total health expenditures in patients with vs without a specific comorbidity (diabetes, renal disease, mental health issues, chronic obstructive pulmonary disease, or cancer). To examine whether mortality modulated healthcare costs, we further stratified total health expenditures by the patient’s vital status (alive/dead) in the year they were an HCU. Cancer services provided on an outpatient basis are provided at specific specialized centres in Alberta and are not fully accounted for in the databases included in our study. For example, our data do not include information on chemotherapy received in ambulatory cancer clinics. Accordingly, we conducted a sensitivity analysis comparing hospitalization costs alone for HCUs with CVD with vs without cancer. In addition to individual comorbidities, we

Table 1. Baseline characteristics of Alberta adult high-cost users (HCUs) of healthcare

| Characteristic | Primary diagnosis of CVD | Secondary diagnosis of CVD | No CVD diagnosis | All |
|---------------|--------------------------|---------------------------|-----------------|-----|
| Number of HCUs | 25,615                   | 42,213                    | 20,708          | 88,536 |
| Female sex    | 10,967 (42.8)            | 20,970 (49.7)             | 10,360 (50.0)   | 42,297 (47.8) |
| Age, y, median| 74.0                     | 74.0                      | 57.0            | 71.0 |
| Urban/metropolitan residence | 17,488 (68.3) | 29,282 (70.7) | 14,346 (69.3) | 61,663 (69.6) |
| Charlson Comorbidity Index | 3 (2.5)               | 3 (1.5)                  | 1 (0.2)         | 2 (1.4) |
| Frailty       | 17,318 (67.6)            | 32,997 (78.2)             | 10,381 (50.1)   | 60,696 (68.6) |
| Myocardial infarction | 7375 (28.8)        | 3868 (9.2)                | —               | 11,243 (12.7) |
| Heart failure  | 11,556 (45.1)            | 7496 (17.8)               | —               | 19,052 (21.5) |
| Peripheral vascular disease | 3929 (15.3)        | 2748 (6.5)                | —               | 6677 (7.5) |
| Cerebrovascular disease | 5827 (22.7)        | 3566 (8.4)                | —               | 9393 (10.6) |
| Hypertension  | 18,252 (71.3)            | 28,851 (68.3)             | —               | 47,103 (53.2) |
| Dementia      | 2876 (11.2)              | 7691 (18.2)               | 2425 (11.7)     | 12,992 (14.7) |
| Chronic pulmonary disease | 7248 (28.3)         | 11,683 (27.7)             | 2634 (12.7)     | 21,565 (24.4) |
| Diabetes mellitus | 9231 (36.0)           | 13,662 (32.4)             | 2600 (12.6)     | 25,493 (28.8) |
| Renal disease  | 4307 (16.8)              | 5015 (11.9)               | 574 (2.8)       | 9896 (11.2) |
| Liver disease  | 1175 (4.6)               | 3254 (7.7)                | 1016 (4.9)      | 5445 (6.2) |
| Cancer        | 3184 (12.4)              | 10,336 (24.5)             | 4999 (24.1)     | 18,519 (20.9) |

Data are presented as n (%), unless otherwise noted. Charlson Comorbidity Index is presented as median (25th percentile, 75th percentile). CVD, cardiovascular disease.
examined healthcare costs by frailty and overall comorbidity burden. For the latter, HCUs with CVD (primary or secondary) were categorized into quartiles, according to their CCI, and average healthcare costs were examined in each group. In addition to unadjusted comparisons, we used a multivariable gamma generalized linear model with log-link to examine the association between the following: demographic factors: FY, individual comorbidities of interest, frailty, overall comorbidity burden, and total healthcare costs.

Finally, for patients who were identified as HCUs with CVD in any of the 4 years of the dynamic cohort (FYs 2011-2014), health expenditures in the 2 years preceding (FY 2009-2010 and FY 2010-2011) and the 2 years after (FY 2015-2016 and FY 2016-2017) meeting the HCU case definition were calculated.

This study was approved by the University of Alberta’s Health Research Ethics Board (Pro00077645). The board determined that due to the retrospective design of the study, subject consent for access to personally identifiable health information would not be reasonable, feasible, or practical, and it therefore waived the need for informed consent. All analyses were done using SAS 9.4 (SAS Software, Cary, CA).

Results

There were 21,560 adult HCUs in FY 2011; 21,988 in FY 2012; 22,613 in FY 2013; and 23,114 in 2014 in Alberta (Fig. 1). After exclusion of patients with incomplete or incorrect data (0.8%), a total of 88,536 adult HCUs were identified in Alberta between April 1, 2011 and March 31, 2015. Among these, 68,357 were HCUs in 1 year of the cohort; 8124 were HCUs in 2 years; 1133 were HCUs in 3 years; and 133 were HCUs in all 4 years of the cohort. Overall, 20,708 (23.4%) had no CVD diagnosis; 25,615 (28.9%) were hospitalized with a primary diagnosis of CVD; and 42,213 (47.7%) were hospitalized with a secondary diagnosis of CVD during the year in which they were identified as an HCU (Table 1). HCUs with CVD were significantly older than HCUs without CVD (median age: 74 years vs 57 years). HCUs with primary CVD included a lower proportion of female patients (42.8%), whereas females accounted for half the number of HCUs either without CVD or with CVD as a secondary diagnosis. The proportions of patients who were frail were 50.1%, 67.6%, and 78.2% among HCUs with no CVD, primary CVD, and secondary CVD, respectively. Among HCUs with primary CVD, 45.1% had heart failure, 9.2% had myocardial infarction, 8.4% had

| Table 2. Total resource utilization and costs among Alberta adult high-cost users (HCUs) |
|-----------------------------------|---------------------------------|----------------|----------------|
| Resource and cost                  | Primary diagnosis of CVD        | Secondary diagnosis of CVD | No CVD diagnosis | All |
|------------------------|-------------------------------|-----------------------------|----------------|
| High-cost users, n      | 25,615                        | 42,213                      | 20,708          | 88,536 |
| Hospitalizations        | 78,625                        | 112,668                     | 49,253          | 240,546 |
| Days in hospital        | 1,368,946                     | 2,920,733                   | 1,319,698       | 5,609,377 |
| Days in intensive care units | 100,163                      | 112,711                     | 28,529          | 241,403 |
| Physician claims        | 3,047,203                     | 5,202,516                   | 2,402,581       | 10,652,100 |
| Ambulatory visits       | 537,779                       | 735,535                     | 334,848         | 1,608,162 |
| ED visits (subset of ambulatory) | 111,983                      | 162,338                     | 79,839          | 354,160 |
| Non-hospital drug dispenses | 2,058,630                    | 3,705,341                   | 1,356,385       | 7,120,356 |
| Procedures              |                               |                             |                 |        |
| PCI                     | 1694                          | 108                         | 0               | 1802 |
| CABBG                   | 3420                          | 34                          | 0               | 3454 |
| Heart transplant        | 58                            | 2                           | 0               | 60 |
| Implantable cardiac device | 2134                         | 146                         | 0               | 2280 |
| Total cost, B           | 2.8                           | 4.9                         | 2.0             | 9.7 |
| Hospitalization cost, B | 2.1 (75.9)                    | 3.9 (80.2)                  | 1.6 (79.6)      | 7.7 (78.8) |
| Ambulatory (including ED) cost, M | 248.1 (8.7)                  | 314.7 (6.4)                | 120.8 (6.0)     | 683.7 (7.0) |
| Claims cost             | 365.4 M (12.8)                | 529.8 M (10.8)              | 235.1 M (11.7)  | 1.1 B (11.6) |
| Non-hospital drug cost, M | 75.8 (2.6)                    | 128.9 (2.6)                 | 53.8 (2.7)      | 258.6 (2.6) |

Values other than costs are n. Costs with (%) are given in 2018 Canadian $. B, billion; CABBG, coronary artery bypass graft; CVD, cardiovascular disease; ED, emergency department; M, million; PCI, percutaneous coronary intervention.

Figure 2. Annual total healthcare costs among high-cost users with cardiovascular disease. CAD, 2018 Canadian dollars; CVD, cardiovascular disease; M, million.
cerebrovascular disease, and 6.5% had peripheral artery disease. Among HCU's with CVD listed in a secondary-diagnosis field, 17.8% had heart failure, 28.8% had myocardial infarction, 22.7% had cerebrovascular disease, and 15.3% had peripheral artery disease. Rates of dementia and diabetes were highest in HCU's with secondary CVD, compared to those with primary CVD or no CVD. The demographic and clinical characteristics of the patients were similar across the 4 years of the study (Supplemental Table S2).

Healthcare costs

HCUs with CVD accounted for substantially higher healthcare resource use and expenditures compared to HCUs without CVD. Over the 4 years, the total cost of hospitalization, ambulatory care, physician services, and drug prescriptions was $2.0 billion among HCUs without CVD, $2.8 billion among those with a primary diagnosis of CVD, and $4.9 billion among HCUs with CVD as a secondary diagnosis (Table 2). Total costs among HCUs with primary CVD increased from $680.5 million in FY 2011-2012 to $750.7 million in FY 2014-2015; total costs among HCUs with secondary CVD increased from $1.2 billion to $1.3 billion during the same time period (Fig. 2; Supplemental Table S3).

In both groups, hospital costs accounted for the largest proportion of total cost each year; however, costs associated with physicians, ambulatory care, and drugs accounted for an additional 24% of healthcare costs among HCUs with primary CVD, and an additional 20% of costs among HCUs with secondary CVD (Fig. 3).

The average (and median) cost per HCU patient per year with primary CVD was $111,500 ($86,100), and $116,700 ($88,500) for an HCU patient with secondary CVD, and $97,000 ($76,400) for an HCU patient with no CVD (Table 3).

Frailty and multimorbidity

The most prevalent comorbidity among HCUs with CVD (either primary or secondary diagnoses) was diabetes (33.8%), followed by chronic obstructive pulmonary disease (27.9%; Table 4). Approximately 20% of HCUs with CVD had cancer, 18.3% had mental health issues, and 13.7% had renal disease. In general, the average annual health expenditure among HCUs with CVD who had these comorbidities was higher than that among HCUs with CVD who did not have these comorbidities. The average hospitalization cost alone among HCUs with CVD and cancer was $86,892, compared

---

**Table 3. Annual costs per patient among Alberta adult high-cost users (HCUs)**

| Cost                           | Primary diagnosis of CVD (n = 25,615) | Secondary diagnosis of CVD (n = 42,213) | No CVD diagnosis (n = 20,708) | All (n = 88,536) |
|-------------------------------|--------------------------------------|----------------------------------------|-----------------------------|------------------|
| Total, mean (SD)              | 111.5 (84.7)                         | 116.7 (113.9)                          | 97.0 (81.6)                 | 110.6 (99.4)     |
| Total, median (IQR)           | 86.1 (64.6–128.1)                    | 88.5 (63.9–134.9)                     | 76.4 (57.9–109.4)          | 84.7 (62.5–126.7) |
| Hospitalization, mean (SD)    | 84.7 (75.0)                          | 93.6 (107.8)                           | 77.2 (78.0)                | 87.2 (92.9)      |
| Hospitalization, median (IQR) | 61.9 (44.3–97.2)                     | 67.5 (46.9–107.5)                     | 57.0 (42.2–87.0)           | 63.1 (44.8–99.4) |
| Ambulatory, mean (SD)         | 9.6 (15.8)                           | 7.4 (13.6)                             | 5.8 (8.5)                  | 7.7 (13.4)       |
| Ambulatory, median (IQR)      | 5.6 (3.1–9.6)                        | 4.0 (2.0–7.4)                          | 3.7 (1.8–6.9)              | 4.4 (2.2–8.0)    |
| Physician, mean (SD)          | 14.1 (10.4)                          | 12.5 (9.8)                             | 11.3 (8.6)                 | 12.7 (9.8)       |
| Physician, median (IQR)       | 11.8 (7.9–17.2)                      | 10.1 (6.5–15.4)                        | 9.1 (5.6–14.5)             | 10.4 (6.6–15.8)  |
| Non-hospital drug, mean (SD)  | 2.9 (7.9)                            | 3.0 (10.2)                             | 2.6 (7.7)                  | 2.9 (9.0)        |
| Non-hospital drug, median (IQR)| 1.9 (0.9–3.5)                      | 1.6 (0.6–3.4)                         | 1.0 (0.3–2.8)              | 1.6 (0.6–3.3)    |

Costs are given in thousands of 2018 Canadian $. n indicates number of HCUs. Total cost = hospitalization, ambulatory (including emergency department), physician, non-hospital drug.

CVD, cardiovascular disease; IQR, interquartile range; SD, standard deviation.
to $91,164 among HCUs with CVD who did not have cancer. The mortality rate among HCUs with CVD with cancer was 46.1%, compared to 21.6% among HCUs with CVD without cancer. Overall, 74.2% of HCUs with CVD were frail, and the average healthcare cost among frail patients was higher ($124,974) compared to that among HCUs with CVD who were not frail ($85,572). The mortality rate among frail patients was 29.6%, compared to 17.7% among those who were not frail. When evaluating multimorbidity burden as a whole, we found that 10.9% of HCUs with CVD had a CCI of 0; 33.5% had a score of 1-2; 27.8% had a score of 3-4; and 27.7% had a score \( \geq 5 \) (Table 4). Both the healthcare cost burden as well as the mortality burden increased substantially across CCI categories among HCUs with CVD.

In multivariable analyses, frailty was one of the most important drivers of healthcare costs, followed by peripheral vascular disease and renal disease (Fig. 4). Older patients and females had lower healthcare costs, whereas urban residency and multimorbidity (CCI \( \geq 2 \)) were associated with higher total healthcare costs.

### Cost trajectories among HCUs

We examined the trajectory of healthcare costs among HCUs with CVD in the years leading up to their inclusion in the dynamic cohort. We found that, compared to the annual per capita health expenditure in Alberta of $4001.30 and $4499 in FY 2009-2010 and FY 2010-2011, respectively, the average annual healthcare cost (unadjusted for inflation) among HCUs with primary CVD was $11,013 and $14,690.40, and $11,775.20 and $16,539.50 among HCUs with secondary CVD in these 2 FYs. In the years following their inclusion in the dynamic cohort, the average annual healthcare cost among HCUs with primary CVD was $27,579.70 and $23,750.10, and $29,140.30 and $26,163.70 among HCUs with secondary CVD, compared to the annual per capita health expenditure in Alberta of $4836.10 and $4977.10 in FY 2015-2016 and FY 2016-2017, respectively.1

### Discussion

Our study examined the prevalence and healthcare costs associated with CVD in a dynamic cohort of complex HCUs from FY 2011-2012 through FY 2014-2015 in Alberta. We found that almost a third of the HCUs were hospitalized with a primary diagnosis of CVD, and an additional half were hospitalized with a secondary diagnosis of CVD, leading to a prevalence of CVD of over 75%. Healthcare costs among HCUs with CVD accounted for $7.7 billion of the total $9.7 billion for all HCUs in Alberta during the 4-year time period. Hospitalization costs accounted for 80% of healthcare expenditures among HCUs with CVD, and costs of physician services, ambulatory care, and drugs accounted for the remaining 20% of total healthcare costs. Frailty and multimorbidity were major drivers of both costs and mortality among HCUs with CVD. The trajectory of increasing healthcare costs in the years prior to becoming a HCU suggest that developing prognostic models to identify CVD patients at high risk of becoming HCUs may be worthwhile.

Estimates of the prevalence of CVD in the general population vary significantly—from an overall 3% in Canada, to 48% among adults age \( \geq 20 \) years in the US.16,17 In our cohort of HCUs, the prevalence of CVD was 76.6%. Although the use of a broader definition may account for some of the observed higher prevalence, the findings of our study demonstrate the significant contribution of CVD to healthcare costs and highlight the need to identify strategies to flatten the cost curve among patients with heart disease.

Of course, this is easier said than done. Following anecdotal accounts of success in reducing healthcare utilization among “hot spotters” or “super-utilizers,” a randomized clinical trial of the Camden Core Model transition care model vs usual care showed no difference in readmission rates in patients in the intervention arm.18 In Canada, high-risk patients were randomized to virtual wards, which extend elements of hospital care into community-based settings, had similar readmission and mortality rates at 30 days and 1 year, compared with those assigned to usual care.19 Similarly, heart failure patients randomized to receive evidence-based transitional care services demonstrated no improvements in readmission, emergency department presentation, or death at 3 months, compared to patients who received usual care.20 However, it has been suggested that the controlled randomized clinical trial framework may not be the best vehicle for studying the impact of interventions targeting HCUs; and real-world, population-based surveillance for upstream identification and intervention may yield better results.21 In longitudinal analysis, we observed a trajectory of increasing

### Table 4. Impact of comorbidities on healthcare costs among high-cost users (HCUs) with cardiovascular disease (CVD)

| Comorbidity | With comorbidity, % | Mean cost, with comorbidity, $ | Mean cost, without comorbidity, $ | Died, with comorbidity, % | Died, without comorbidity, % |
|-------------|---------------------|-------------------------------|----------------------------------|---------------------------|-----------------------------|
| Mental health | 18.3 | 131,865 | 110,983 | 23.4 | 27.2 |
| COPD | 27.9 | 116,633 | 114,091 | 31.8 | 24.5 |
| Diabetes | 55.8 | 123,879 | 110,176 | 27.0 | 26.3 |
| Renal | 13.7 | 133,263 | 111,859 | 34.7 | 25.2 |
| Cancer | 19.9 | 110,615 | 115,843 | 46.1 | 21.6 |
| Frailty* | 74.2 | 124,974 | 85,572 | 29.6 | 17.7 |
| Charlson score | | | | | |
| 0 | 10.9 | 106,165 | — | 8.5 | — |
| 1–2 | 35.5 | 106,134 | — | 18.4 | — |
| 3–4 | 27.8 | 118,078 | — | 26.6 | — |
| 5+ | 27.7 | 125,372 | — | 43.3 | — |

Costs are given in 2018 Canadian $.  
COPD, chronic obstructive pulmonary disease.  
* Based on the Hospital Frailty Risk Score (HFRS).
healthcare costs in the years prior to patients being identified as HCUs. Both the development of “learning” healthcare systems that integrate primary and tertiary health data with exogenous factors, such as social determinants and environmental data, and the employment of novel methods, such as machine learning, may offer opportunities for early identification of potential HCUs.

We have previously shown that physician continuity and initiatives to increase access to specialized heart failure clinics are associated with a decrease in mortality and readmission rates. Further work is needed to examine their impact on healthcare costs, especially among HCUs. We also have documented the impact of alternative venues of care, such as hospices and long-term care facilities on end-of-life costs in heart failure patients, and the cost implications of excessive or unnecessary diagnostic testing in patients with acute coronary syndromes. Better integration between research and health policy is needed to move the needle from documentation to developing effective interventions.

Approximately 20% of the HCUs with CVD had cancer. The lower average healthcare costs observed among HCUs with cancer, compared to HCUs without cancer, are likely due to at least 2 factors. The first is the incompleteness of capture of ambulatory services for cancer patients in our data. Hence, the difference in costs between those with vs without cancer was substantially attenuated when our

| CVD Category (ref: No CVD Diagnosis) | Cost Ratio (95% CI) |
|-------------------------------------|---------------------|
| Primary CVD Diagnosis               | 1.06 (1.04, 1.07)   |
| Secondary CVD Diagnosis             | 1.11 (1.10, 1.12)   |

| Age Spline                          |                      |
|-------------------------------------|----------------------|
| Age 75 vs. Age 55                   | 0.83 (0.82, 0.84)    |
| Female                              | 0.97 (0.96, 0.98)    |
| Urban                               | 1.05 (1.04, 1.06)    |
| Death in Year                       | 0.98 (0.97, 0.99)    |

| Fiscal Year (ref: 2011/12)          |                      |
|-------------------------------------|----------------------|
| 2012/13                             | 1.00 (0.99, 1.01)    |
| 2013/14                             | 0.99 (0.98, 1.00)    |
| 2014/15                             | 1.05 (1.04, 1.06)    |

| Comorbidities                       |                      |
|-------------------------------------|----------------------|
| Myocardial Infarction               | 1.00 (0.99, 1.01)    |
| Congestive Heart Failure            | 1.04 (1.03, 1.05)    |
| Peripheral Vascular Disease        | 1.15 (1.14, 1.17)    |
| Cerebrovascular Disease             | 1.05 (1.04, 1.06)    |
| Dementia                            | 0.99 (0.98, 1.00)    |
| Chronic Pulmonary Disease           | 1.00 (0.99, 1.01)    |
| Diabetes                            | 1.05 (1.04, 1.06)    |
| Renal Disease                       | 1.12 (1.11, 1.14)    |
| Liver Disease                       | 1.01 (1.00, 1.03)    |
| Cancer                              | 0.98 (0.97, 0.99)    |

| Charlson Comorbidity Index (ref: 0) |                      |
|-------------------------------------|----------------------|
| 1                                   | 1.02 (1.01, 1.03)    |
| 2                                   | 1.06 (1.05, 1.08)    |
| 3                                   | 1.06 (1.04, 1.08)    |
| 4                                   | 1.05 (1.03, 1.07)    |
| 5+                                  | 1.06 (1.04, 1.08)    |
| Frail                               | 1.48 (1.47, 1.50)    |

Figure 4. Association of demographic factors, frailty, and comorbidities with total healthcare costs. CI, confidence interval; CVD, cardiovascular disease; ref, referent.
examination was restricted to hospitalization costs alone. The second factor is the high mortality rate (46.1%) among HCUs with CVD and cancer. Additional research, as part of the emerging field of cardio-oncology, may assist in providing better understanding of the reasons for this high prevalence, and its substantial impact on mortality and costs, of cancer among HCUs with CVD.

Limitations
Our study has several limitations. First, the CIHR/CIHI Dynamic Cohort HCUs were identified as those accounting for the top 10% of acute care (hospitalization) costs only, and not for total healthcare costs. We categorized HCUs who had a CVD diagnosis in an inpatient setting as an HCU with CVD for the entire year. Although it is highly unlikely that such cases occurred, HCUs with CVD who were treated entirely in the outpatient setting in a specific year would be categorized in the HCU no CVD group. Although our study provides an estimate of total healthcare costs for HCUs in Alberta by examining ambulatory, physician, and drug costs in HCUs, we could not estimate other costs, such as those related to laboratory tests, diagnostic imaging, long-term care, or home care. We only included the cost of physicians, and not of other community-based allied healthcare professionals, such as pharmacists, physiotherapists, dieticians, social workers, and others who were likely involved in the care of these patients. Our study does not take into account any indirect costs, such as days away from work, for either the patients or their caregivers. As discussed above, healthcare costs for cancer patients are underestimated, as they may not include all costs of non-acute hospitalizations or outpatient visits. Lastly, our inpatient and ambulatory cost estimates are based on averages, which may underestimate or overestimate true costs, depending on the facilities where care was provided.

Conclusions
CVD accounts for a large proportion of healthcare costs among HCUs. Although hospitalization accounts for the highest proportion of costs among HCUs, they also incur substantial ambulatory, physician, and drug costs. HCUs with CVD have high rates of other comorbidities that contribute substantially to healthcare costs and adverse outcomes. Further research, using longitudinal, population-level cohorts, is needed to identify these highly complex patients at more proximal time points and aid in the design of interventions to modify elements of their care before they become HCUs.

Acknowledgements
This study is based in part on data provided by Alberta Health and Alberta Health Services. We thank the Customer Relationship Management and Data Access Unit at Alberta Health for creating the linked database. The interpretation and conclusions are those of the researchers and do not represent the views of the government of Alberta. Neither the government of Alberta nor Alberta Health expresses any opinion in relation to this study.

We thank Dr Leah Luoma and Ms. Ellen Pyear for assistance with generating the figures for the article.

Funding Sources
Dr Kaul is a CIHR Chair in Sex and Gender Science and is supported by the Heart & Stroke Chair in Cardiovascular Research. Dr McAlister is supported by an Alberta Health Services Chair in Cardiovascular Outcomes Research.

Disclosures
The authors have no conflicts of interest to disclose.

References
1. Canadian Institute for Health Information. Health spending. Available at: https://www.cihi.ca/en/health-spending. Accessed December 18, 2020.
2. Keehan SP, Cuckler GA, Poisal JA, et al. National health expenditure projections, 2019–28: expected rebound in prices drives rising spending growth. Health Aff 2020;39:704-14.
3. Berk ML, Monheıt AC. The concentration of health care expenditures, revisited. Health Aff 2017;20:9-18.
4. Siekmann N, Hilger R. High users of healthcare: strategies to improve care, reduce costs. Clev Clin J Med 2018;85:25-31.
5. Gantayet A, Ang M, Cao X, Halperin I. Persistent and non-persistent high-users of acute care resources: a deeper dive into the patient and system factors. Healthc Q 2017;20:31-6.
6. Reid R, Evans R, Barer M, et al. Conspicuous consumption: characterizing high users of physician services in one Canadian province. J Health Serv Res Policy 2003;8:215-24.
7. Druss BG, Marcus SC, Olsson M, Pincus HA. The most expensive medical conditions in America. Health Aff 2017;2017:21:105-11.
8. Canadian Institutes of Health Research. Dynamic cohort of complex, high system users—2011-2015. Available at: https://cihr-irsc.gc.ca/e/50129.html. Accessed March 1, 2019.
9. Canadian Institute for Health Information. Cost of a standard hospital stay. Available at: https://yourhealthsystem.cihi.ca/hsp/inbrief?lang=en#!/indicators/015/cost-of-a-standard-hospital-stay-cshs/mapLevel2;provinceC9001;/. Accessed December 18, 2020.
10. Canadian Institute for Health Information. Cost of a standard hospital stay: appendices to indicator library methodology notes. Available at: https://www.cihi.ca/sites/default/files/document/general-methodology-notes.pdf. Accessed December 18, 2020.
11. Alberta Health. Alberta Health Care Insurance Plan Statistical Supplement. Available at: https://open.alberta.ca/publications/0845-4775. Accessed December 18, 2020.
12. Quan H, Sundararajan V, Halfon P, et al. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. Med Care 2005;43:1130-9.
13. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chron Dis 1987;40:373-83.
14. Gilbert T, Neuhuber J, Kraindler J, et al. Development and validation of a Hospital Frailty Risk Score focusing on older people in acute care settings using electronic hospital records: an observational study. Lancet 2018;391:1775-82.
15. McAlister F, van Walraven C. External validation of the Hospital Frailty Risk Score and comparison with the Hospital-patient One-year Mortality.
Risk Score to predict outcomes in elderly hospitalised patients: a retrospective cohort study. BMJ Qual Saf 2019;28:284.

16. Roth GA, Johnson C, Abajobir A, et al. Global, regional, and national burden of cardiovascular diseases for 10 causes, 1990 to 2015. J Am Coll Cardiol 2017;70:1-25.

17. Virani SS, Alonso A, Benjamin EJ, et al. Heart disease and stroke statistics—2020 update. Circulation 2020;141:e139-596.

18. Finkelstein A, Taubman S, Doyle J. Health care hotspotting—a randomized, controlled trial. N Engl J Med 2020;382:2172-4.

19. Dhalla IA, O’Brien T, Morra D, et al. Effect of a postdischarge virtual ward on readmission or death for high-risk patients: a randomized clinical trial. JAMA 2014;312:1305-12.

20. Spall HGCV, Lee SF, Xie F, et al. Effect of patient-centered transitional care services on clinical outcomes in patients hospitalized for heart failure. JAMA 2019;321:753-61.

21. Grant RW, McCloskey J, Hatfield M, et al. Use of latent class analysis and k-means clustering to identify complex patient profiles. JAMA Netw Open 2020;3:e2029068.

22. McAlister FA, Bakal JA, Kaul P, et al. Changes in heart failure outcomes after a province-wide change in health service provision: a natural experiment in Alberta, Canada. Circ Heart Fail 2013;6:76-82.

23. McAlister FA, Youngson E, Kaul P, Ezekowitz JA. Early follow-up after a heart failure exacerbation. Circ Heart Fail 2018;9:e003194.

24. McAlister FA, Youngson E, Bakal JA, et al. Impact of physician continuity on death or urgent readmission after discharge among patients with heart failure. CMAJ 2013;185:E681-9.

25. Sidhu RS, Youngson E, McAlister FA. Physician continuity improves outcomes for heart failure patients treated and released from the emergency department. JACC Heart Fail 2014;2:368-76.

26. Kaul P, McAlister FA, Ezekowitz JA, et al. Resource use in the last 6 months of life among patients with heart failure in Canada. Arch Intern Med 2011;171:211-7.

27. BaineKR, Durham D, Zheng Y, et al. Utilization and costs of noninvasive cardiac tests after acute coronary syndromes: insights from the Alberta COAPT Study. Can J Cardiol Open 2019;1:76-83.

28. Dhoot A, Liu S, Savu A, et al. Cardiac stress testing after coronary revascularization. Am J Cardiol 2020;136:9-14.

Supplementary Material
To access the supplementary material accompanying this article, visit CJC Open at https://www.cjcopen.ca/ and at https://doi.org/10.1016/j.cjco.2021.09.017.