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Technical Appendix

Methodological overview of the Ontario Burden of Disease Model from the Ontario Burden of Illness Report

The purpose of this document is to provide a methodological overview of the data and analytical approaches used to develop and implement the Ontario Burden of Disease Model (OBDM) for the Projected Burden of Illness Report.[1] **Figure 1** is a flow chart depicting the methodological approach used in the OBDM and provides a high-level summary of the modelling strategy. The overall approach can be summarized in the following stages:

1) Historical trends in chronic disease were captured from health administrative data for the Ontario population between 2002 and 2022.
2) Chronic disease status as of April 1, 2022 was combined with health administrative data capturing population health and health system outcomes between 2022 and 2023 to group the Ontario population (2002-2022) into three morbidity groups: no illness, some illness, and major illness.
3) Historical trends in chronic disease and morbidity groups were used to create sex- and age-group-specific projections of disease for 2023-2040, which were combined with demographic projections to quantify population-level trends.

Section 1 of this report provides greater detail about each of these steps. Section 2 includes information on how the model has been adapted for sub-provincial populations, including geographically defined populations (e.g., Ontario Health Region, Public Health Unit) and hospital-attributable populations (e.g., Ontario Health Teams).

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Section 1. The Ontario Burden of Disease Model methodological approach.

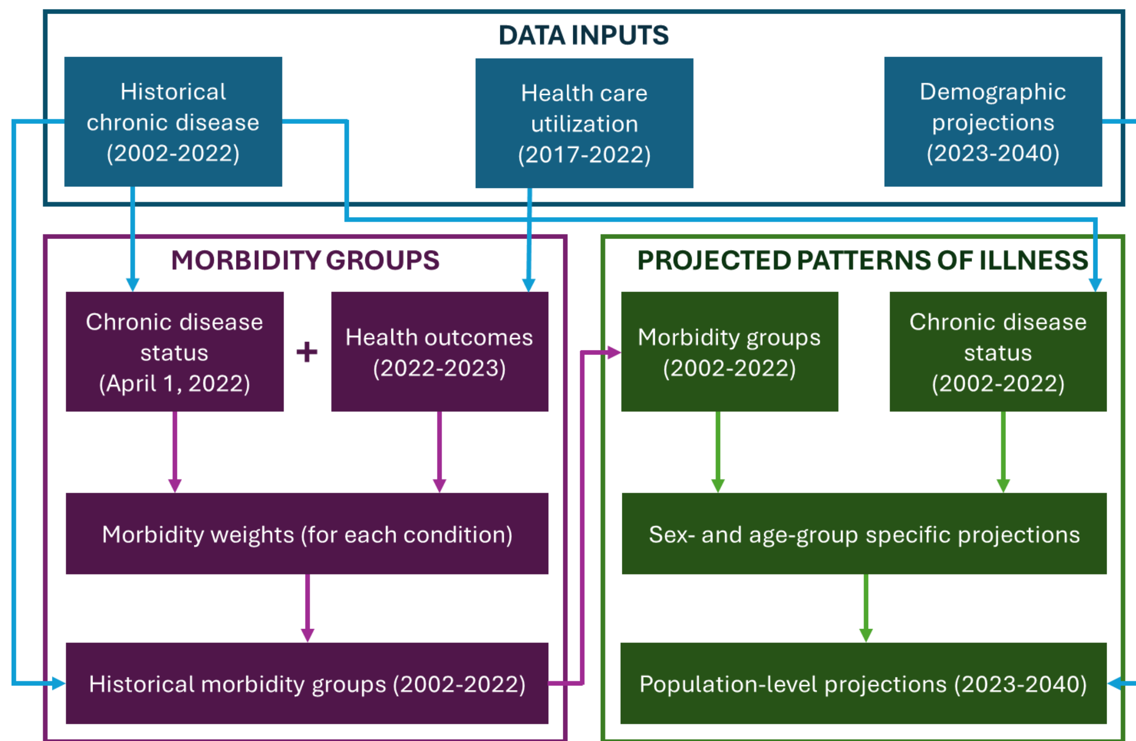

Figure 1. Methodological flow chart to generate projected burden of illness estimates.

Study population

The OBDM is based on data capturing all adults aged 30+ living in Ontario between 2002 and 2022. To be included in the provincial models, individuals had to be eligible for coverage under the Ontario Health Insurance Plan (OHIP) for at least 1 full year in the lookback period. For geographic sub-population models (e.g., Public Health Units), individuals were excluded if their OHIP registration data did not include any postal code information.

Data inputs

Historical chronic disease

Health administrative data held at ICES were used to identify historical chronic disease status based on diagnoses recorded in healthcare interactions. Datasets were linked using encoded identifiers and analyzed at ICES (formerly the Institute for Clinical Evaluative Sciences), a prescribed entity authorized under provincial legislation to collect personal health information for the purposes of health system policy, planning and evaluation. ICES data captures individuals eligible for OHIP at any time since April 1992. These data include hospitalizations (Discharge Abstract Database, DAD), emergency department visits (National Ambulatory Care Reporting System, NACRS), outpatient visits including primary and specialist care (Ontario Health Insurance Plan (OHIP), Medical Services Data (MSD)), population demographic data (immigration, age, sex,

geography), individual- and area-level socioeconomic measures, and behavioural risk factors (Canadian Community Health Survey, CCHS).

Chronic disease status was ascertained for 22 conditions using standardized algorithms. The definitions used for each chronic disease are included in **Supplementary Table S1**. Validated algorithms for the Ontario population were used to identify patients with a history of acute myocardial infarction (AMI),[2] asthma[3], chronic obstructive pulmonary disease[4], congestive heart failure (CHF),[5] Crohn's or colitis,[6] diabetes,[7] dementia,[8] and hypertension.[9] The Ontario Cancer Registry[10] was used to identify cancer. Assistive device billings were used to identify hearing loss. A standardized approach was used to identify an additional 12 conditions: anxiety and mood disorders, cardiac arrhythmia, chronic coronary syndrome, constipation, epilepsy, osteoporosis, osteo- and other non-rheumatoid arthritis, renal failure, rheumatoid arthritis, schizophrenia and other psychotic disorders, stroke, and substance use disorders. Other than cancer and hearing loss, all definitions were based on ICD-9 and ICD-10 codes recorded in health encounter data.

Health care utilization

Health care utilization data were used to identify health system outcomes for the purpose of creating the population illness groups. Primary care visits were captured using outpatient physician billings with specialist codes indicating primary care or pediatrics. Unplanned hospitalizations were identified from hospital discharge records that did not include a flag for a scheduled visit.

Demographic projections

Demographic projections were based on the 2023-2046 population projections published by the Ontario Ministry of Finance in summer 2023, which are based on Statistics Canada's [11] postcensal estimates for July 1, 2022. Specifically, the OBDM uses reference-scenario projections from the Ministry of Finance, although high- and low-growth scenarios are also available. The projections are available at the census division level (n=49) and account for expected population trends in fertility, mortality, and migration, including in- and out-migration at both the national and interprovincial levels.

Historical population estimates based on Statistics Canada's intercensal population counts were also used for historical periods (2002-2022). Based on these data, the historical and projected Ontario populations are shown in **Figure 2**.

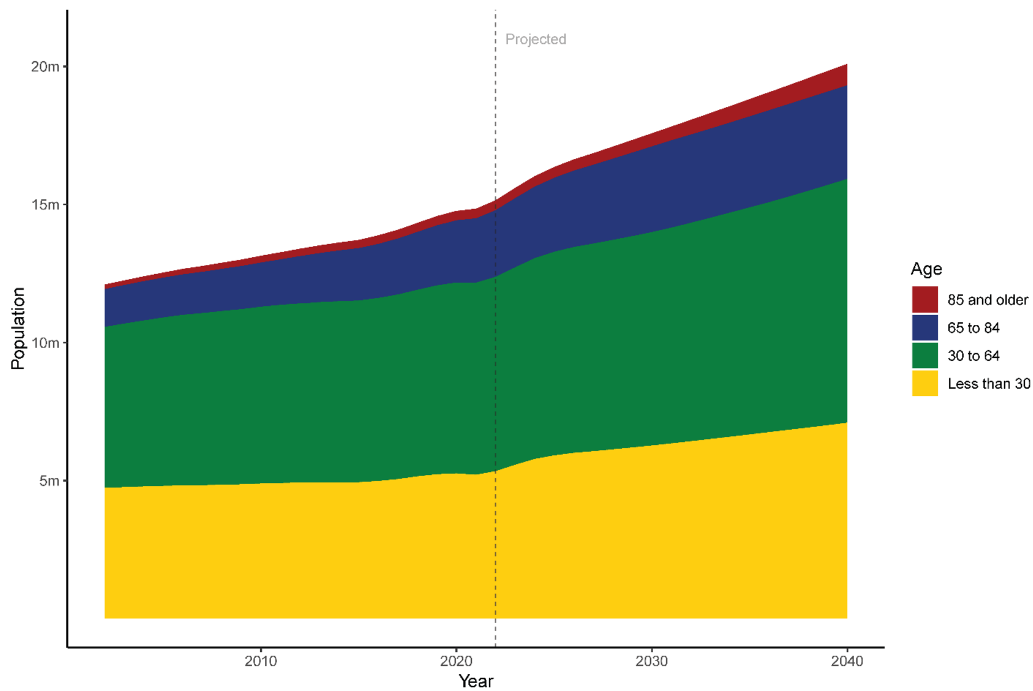

Figure 2. Historical population (2002 to 2022) and population projections (2023 to 2040) for the population living in Ontario, by age group.

Morbidity groups

Morbidity groups were defined using an approach based on the Cambridge Multimorbidity Score (CMS) and adapted for the Ontario population.[12] The CMS, which is based on the UK population, assigns weights to chronic conditions based on their impacts on health service utilization and mortality risk; scores in the CMS equation range from 0.08 for hypertension, 1.53 for cancer, and 2.50 for dementia. The adapted approach used in ODBM represents a novel, health system-focused, and Canada-specific weighted equation that identifies multimorbidity groups based on underlying conditions and their relationship with healthcare utilization and mortality. This is an advantage over older approaches (e.g., number of chronic conditions,[13] Charlson index[14]) that use equal or mortality-based weights to summarize multimorbidity.[15] For each year, this weighted equation was used to categorize the provincial population into three groups based on sex, 5-year age group, and multimorbidity: no illness, some illness, and major illness.

Developing the morbidity weights

For the adult (30+) population living in Ontario and eligible for OHIP on April 1, 2022, chronic disease status was identified for 22 chronic conditions, as previously discussed. Three health outcomes were ascertained from health administrative data between April 1, 2022 and March 31, 2023: the number of primary care visits, unplanned hospitalizations, and deaths.

Regression models were used to quantify associations between prevalent chronic disease and each of the three outcomes. For unplanned hospitalization and death, logistic regression models

were used. For the number of primary care visits, Poisson regression models were used. The covariates included in the models were age group, sex, and the 22 chronic disease flags.

Disease coefficients from each outcome model were standardized to create an outcome-specific weight for each condition. Then, weights from the three models were pooled to estimate a general outcome weight for each condition. The equation weights from this updated morbidity score, compared with those from other similar scores, are presented in **Supplemental Table S2**.

For the historical period (2002-2022), the general outcome weights were applied to the Ontario population to calculate a person-level, continuous morbidity score. Based on the distribution of these scores, the population was grouped into three morbidity groups based on previously validated cutoffs: No illness (CMS=0), some illness (0<CMS≤1.5), and major illness (CMS>1.5).[12] These morbidity groups align well with healthcare costs in 2022, as shown in **Figure 3.**

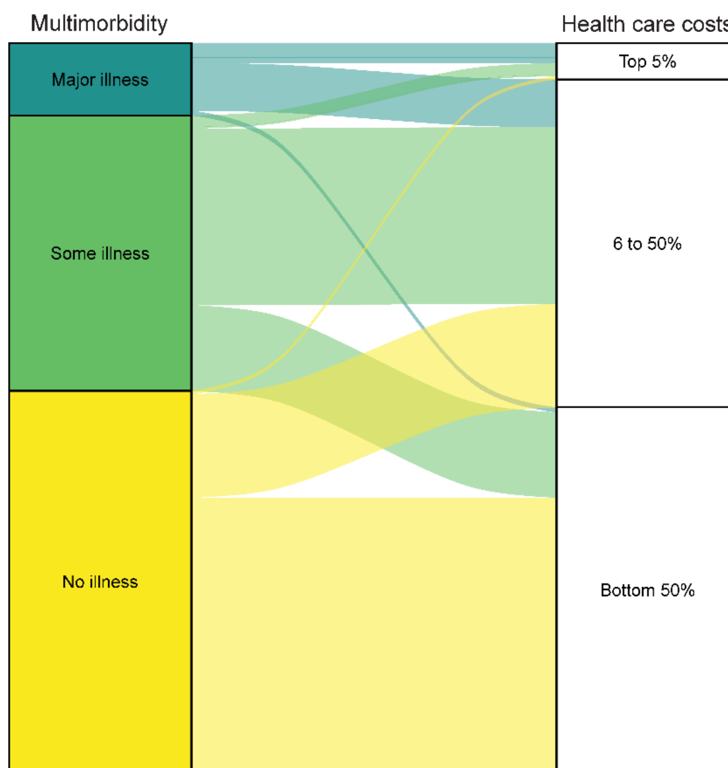

Figure 3. Health care costs[1] (2022) for the Ontario population aged 30 and older, grouped into multimorbidity classes using an Ontario-specific multimorbidity equation.

[1]Health care costs are estimated using data capturing healthcare encounters and OHIP billings.[16] Healthcare system users are grouped based on the percentile of their healthcare utilization in 2022 (i.e., 'Top 5%' groups contains health care system users in the top 5% of all users that year).

Projected patterns of illness

Projection models were used to quantify the expected number of cases and the population prevalence of each chronic condition between 2023 and 2040. In parallel, models were also used to project the three morbidity groups. The projections used a unified modelling approach.

Sex- and age group-specific projections

Sex- and age-group–specific prevalence projections were generated separately for each disease outcome and morbidity grouping. For single chronic disease outcomes (n = 22), binary logistic regression models were fit. For the three mutually exclusive morbidity groupings, multinomial logistic regression models were used, with the lowest morbidity category specified as the reference group. All models included categorical indicators for 5-year age group and sex, as well as calendar year modelled as a continuous variable to capture temporal trends. Using the fitted models, predicted probabilities of disease or morbidity group membership were generated for each combination of sex and 5-year age group for each year between 2023 and 2040. Projections assume the continuation of observed age-, sex-, and time-specific trends over the projection period (i.e. status quo scenario).

Population-level projections

Population-level projections were derived by combining the sex- and age-specific prevalence estimates with external demographic projections. Official population projections stratified by sex, 5-year age group, and calendar year were used as inputs. For each projection year, age- and sex-specific prevalence estimates were applied to the corresponding projected population counts to estimate the number of individuals living with each condition and morbidity group. These estimates were then aggregated across age and sex strata to produce total projected case counts and population prevalence for each outcome. This approach allows projected changes in disease burden to reflect both demographic shifts (population growth and aging) and underlying changes in age-specific disease prevalence. Results are presented as both the absolute number of individuals affected and the overall population prevalence.

Model checking and sensitivity analyses

Model fit was assessed by comparing observed and predicted prevalence across age, sex, and time strata within the historical data period. Sensitivity analyses are ongoing to assess the robustness of projections to alternative model specifications and functional forms for time.

Section 2. Adapting the Ontario Burden of Disease Model to sub-provincial populations.

The OBDM has been adapted to develop similar projections of chronic disease and illness groups for sub-provincial populations in Ontario. These populations can generally be subdivided into those that are geographically defined (e.g., Ontario Health Region, Public Health Unit) and those defined by hospital-attributable populations (e.g., Ontario Health Teams).

Geographically defined populations

Geographically defined populations involve segmenting the Ontario population based on individuals' place of residence. For the historical data, individuals were assigned annually to geographic sub-populations based on their most likely postal code in that year, as captured from health administrative data at ICES. Data sources used to capture updated postal code information include OHIP registration data, inpatient hospital stays, and emergency department visits.

The Ministry of Finance population projections are available at the census division level (n=49). Spatial analysis techniques were used to reconstruct historical and future population counts, by age and sex, for each geographic unit.

Regression models for geographically defined populations excluded individuals with no recorded postal code information. The models were estimated separately for each geographic unit.

Hospital-attributable populations

Hospital-attributable populations capture individuals who have accessed care, or are likely to access care, at a given hospital or group of hospitals. For the historical data, individuals were assigned annually to hospital-attributable populations if they were assigned to the associated physician network,[17] had an inpatient acute care or mental health stay, or accessed emergency department services. Regression models were estimated separately for each hospital-attributable population.

Supplementary table S1. Chronic disease definitions.

Chronic condition	Case definition[1,2,3]	Reference
Myocardial infarction (AMI)	(≥1 hospitalizations, with a most responsible diagnosis of MI) *and* (no MI hospitalization in the previous year) *ICD-9:* 410 *ICD-10:* I21	Austin PC, Daly PA, Tu JV. A multicenter study of the coding accuracy of hospital discharge administrative data for patients admitted to cardiac care units in Ontario. Am Heart J. 2002 Aug;144(2):290-6.
Asthma	(≥1 hospitalizations) *or* (≥2 outpatient visits, within a 2-year period) *ICD-9:* 493 *ICD-10*: J45, J46	Gershon AS, Wang C, Guan J, Vasilevska-Ristovska J, Cicutto L, To T. Identifying patients with physician-diagnosed asthma in health administrative databases. Can Respir J 2009;16:183-8.
Anxiety and mood disorders[4]	(≥1 hospitalizations) *or* (≥1 outpatient visits to a psychiatrist) *or* ((≥1 outpatient visits to a FP/GP) *ICD-9 (DSM-IV):* 296, 300.4, 301.13 *ICD-10:* F30-F34, F38, F39, F53.0 *OHIP dx:* 296, 300, 311 Assessed annually; active diagnosis considered as care received within the past 2 years.	ICES Mental Health and Addictions Program Framework Research Team. Mental Health Dashboard. Last updated October 30, 2024. Available from: https://www.ices.on.ca/dashboards/mental-health-dashboard/
Cancer	Primary incident cancer, excluding non-melanoma skin cancer	Hall S, Schulze K, Groome P, Mackillop W, Holowaty E. Using cancer registry data for survival studies: the example of the Ontario Cancer Registry. J Clin Epidemiol 2006;59:67–76.
Cardiac arrythmia	(≥1 hospitalizations) *or* (≥2 outpatient visits, within a 2-year period) *ICD-9:* 427.3 *ICD-10:* I48.0, I48.1 *OHIP dx:* 427	Rosella L, Kornas K, Huang A, Bornbaum C, Henry D, Wodchis WP. Accumulation of chronic conditions at the time of death increased in Ontario from 1994 to 2013. Health Aff (Millwood) 2018;37:464–72.
Chronic coronary syndrome	(≥1 hospitalizations) *or* (≥2 outpatient visits, within a 2-year period) *ICD-9:* 411, 412, 413, 414 *ICD-10:* I20, I22, I23, I24, I25	Rosella L, Kornas K, Huang A, Bornbaum C, Henry D, Wodchis WP. Accumulation of chronic conditions at the time of death increased in Ontario from 1994 to 2013. Health Aff (Millwood) 2018;37:464–72.
Chronic obstructive pulmonary disorder (COPD)	***Ages 35+:*** (≥1 hospitalizations) *or* (≥1 outpatient visits) ICD-9: 491, 492, 496 ICD-10: J41, J42, J43, J44	Gershon A, Wang C, Guan J, Vasilevska-Ristovska J, Cicutto L, To T. Identifying individuals with physcian diagnosed COPD in health administrative databases. COPD 2009;6:388-94.

Supplementary table S1. Chronic disease definitions.

Chronic condition	Case definition[1,2,3]	Reference
Crohn's and colitis[4]	***Children/youth (<18)*** [3]***:*** (≥1 OHIP procedure *and* [≥2 hospitalizations *or* ≥4 outpatient/ED visits, within a 3-year period]) *or* (≥3 hospitalizations *or* ≥7 outpatient/ED visits, within a 3-year period) ***Adults (18-64):*** (2 years of OHIP eligibility *and* ≥5 hospital/ED/outpatient visits, within a 4-year period) *or* (<2 years of OHIP eligibility *and* ≥3 hospital/ED/outpatient visits, within a 4-year period) ***Older adults (65+)*****:** (2 years of OHIP eligibility *and* ≥5 hospital/ED/outpatient visits, within in a 4-year period *and* ≥1 drug dispensation for IBD medication) *or* (<2 years of OHIP eligibility *and* ≥3 hospital/ED/outpatient visits, within in a 4-year period *and* ≥1 drug dispensation for IBD medication) *ICD-9:* 555, 556 *ICD-10:* K50, K51 *OHIP feecode (for childhood onset only[3])*: Z535, Z555, Z580, E740, E741, E747, E705 *ODB DIN:* see citation	Benchimol EI, Guttmann A, Mack DR, Nguyen GC, Marshall JK, Gregor JC, Wong J, Forster AJ, Manuel DG. Validation of international algorithms to identify adults with inflammatory bowel disease in health administrative data from Ontario, Canada. J Clin Epidemiol. 2014 Aug;67(8):887-96.
Congestive heart failure (CHF)	***Ages 40+:*** (≥1 hospitalizations) *or* (≥1 or more outpatient/ED visits, followed by hospitalization/ED/outpatient visit within 1 year) *ICD-9:* 428 *ICD-10:* I50.0, I50.1, I50.9 *OHIP feecode:* Q050	Schultz SE, Rothwell DM, Chen Z, Tu K. Identifying cases of congestive heart failure from administrative data: a validation study using primary care patient records. Chronic diseases and injuries in Canada 2013;33:160-6.
Constipation[4]	≥3 outpatient visits, at least 4 weeks apart, within a 1-year period *OHIP dx:* 564	Nasr A, Grandpierre V, Sullivan KJ, Wong CA, Benchimol EI. Long-term outcomes of patients surgically treated for Hirschsprung disease. Journal of the Canadian Association of Gastroenterology. 2021 Oct 1;4(5):201-6.

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Supplementary table S1. Chronic disease definitions.

Chronic condition	Case definition[1,2,3]	Reference
Dementia	***Ages 40+:*** (≥1 hospitalizations) *or* (≥1 drug dispensation for cholinesterase inhibitors) *or* (≥3 outpatient visits, at least 30 days apart, in a two-year period) *ICD-9:* 461, 290.0-290.4, 294, 331.0, 331.1, 331.5, 331.82 *ICD-10:* F00, F01, F02, F03, G30 *OHIP dx:* 290, 331 *ODB DIN:* see reference	Jaakkimainen RL, Bronskill SE, Tierney M, Hermann N, Green D, Young J, Ivers N, Butt D, Tu K. Identification of physician-diagnosed Alzheimer's disease and related dementias in population-based administrative data: a validation study using family physicians' electronic medical records. Journal of Alzheimer's Disease, 54(2016): 337-349.
Diabetes mellitus	***Children/youth (≤18)[3]:*** (≥4 outpatient visits, within a 2-year period) *or* (≥1 OHIP procedure) ***Adults (19+):*** (≥2 outpatient visits, within a 1-year period) *or* (≥1 hospitalization) Gestational diabetes records are excluded. *ICD-9:* 250 *ICD-10:* E10, E11, E13, E14 *OHIP feecode (for childhood onset only[3])*: Q040, K029, K030, K045, K046	Lipscombe LL, Hwee J, Webster L, Shah BR, Booth GL, Tu K. Identifying diabetes cases from administrative data: a population-based validation study. BMC health services research. 2018 Dec;18:1-8.
Epilepsy[4]	(≥1 hospitalizations) *or* (≥3 outpatient visits, at least 30 days apart, within a 2-year period) *ICD-9:* 345 (excluding 345.2, 345.3) *ICD-10:* G40 *OHIP dx:* 345	Tu K, Wang M, Jaakkimainen RL, Butt D, Ivers NM, Young J, Green D, Jetté N. Assessing the validity of using administrative data to identify patients with epilepsy. Epilepsia. 2014 Feb;55(2):335-43.
Hearing loss	Hearing amplification device (unilateral or bilateral) claim through the assistive devices program	Newsted, D., Cooke, B., Rosen, E., Nguyen, P., Campbell, R. J., & Beyea, J. A. (2022). Hearing aid utilization in Ontario – a population based study. Disability and Rehabilitation: Assistive Technology, 19(2), 383–389.
Hypertension	***Adults (20+):*** (≥1 hospitalization) *or* (1 outpatient visit, followed by hospitalization or outpatient visit within 2 years) Gestational hypertension records are excluded. *ICD-9:* 401, 402, 403, 404, 405 *ICD-10:* I10-I13, I15	Tu K, Campbell NR, Chen Z-L, Cauch-Dudek KJ, McAlister FA. Accuracy of administrative databases in identifying patients with hypertension. Open Medicine 2007;1:18-26.

Supplementary table S1. Chronic disease definitions.

Chronic condition	Case definition[1,2,3]	Reference
Osteo- and other non-rheumatoid arthritis	(≥1 hospitalizations) *or* (≥2 outpatient visits, within a 2-year period) *ICD-9:* 274, 710, 711, 715, 716, 718, 720, 727, 728, 729, 739 *ICD-10:* M00-M03, M07, M10-M25, M30-M36, M65-M79	Rosella L, Kornas K, Huang A, Bornbaum C, Henry D, Wodchis WP. Accumulation of chronic conditions at the time of death increased in Ontario from 1994 to 2013. Health Aff (Millwood) 2018;37:464–72.
Osteoporosis	(≥1 hospitalizations) *or* (≥2 outpatient visits, within a 2-year period) *ICD-9:* 733 *ICD-10*: M81, M82	Rosella L, Kornas K, Huang A, Bornbaum C, Henry D, Wodchis WP. Accumulation of chronic conditions at the time of death increased in Ontario from 1994 to 2013. Health Aff (Millwood) 2018;37:464–72.
Renal failure	(≥1 hospitalizations) *or* (≥2 outpatient visits, within a 2-year period) *ICD-9:* 403, 404, 584, 585, 586, V451 *ICD-10:* N17, N18, N19, T82.4, Z49.2, Z99.2 *OHIP dx:* 403, 404, 584, 585	Rosella L, Kornas K, Huang A, Bornbaum C, Henry D, Wodchis WP. Accumulation of chronic conditions at the time of death increased in Ontario from 1994 to 2013. Health Aff (Millwood) 2018;37:464–72.
Rheumatoid arthritis	***Adults (15+):*** (≥1 hospitalizations) *or* (≥3 outpatient visits, within a 2-year period, with ≥1 claims made by a musculoskeletal specialist) *ICD-9:* 714 *ICD-10:* M05, M06	Widdifield J, Bombardier C, Bernatsky S, Paterson JM, Green D, Young J, Ivers N, Butt DA, Jaakkimainen RL, Thorne JC, Tu K. An administrative data validation study of the accuracy of algorithms for identifying rheumatoid arthritis: the influence of the reference standard on algorithm performance. BMC Musculoskelet Disord. 2014 Jun 23;15:216.
Schizophrenia and other psychotic disorders[4]	(≥1 hospitalization) *or* (≥1 outpatient visits to a psychiatrist) *or* (≥1 outpatient visits to a FP/GP) *ICD-9 (DSM-IV):* 295, 297, 298 *ICD-10:* F20 (excluding F20.4), F22-F25, F28, F29, F531 Assessed annually; active diagnosis considered as care received within the past 2 years.	ICES Mental Health and Addictions Program Framework Research Team. Mental Health Dashboard. Last updated October 30, 2024. Available from: https://www.ices.on.ca/dashboards/mental-health-dashboard/
Substance use disorders[4]	(≥1 hospitalization) *or* (≥1 outpatient visits to a psychiatrist) *or* (≥1 outpatient visits to a FP/GP) *ICD-9 (DSM-IV):* 291 (excluding 291.82), 292 (excluding 292.85), 303, 304, 305 *ICD-10:* F55, F10-F19 *OHIP dx:* 303, 304 Assessed annually; active diagnosis considered as care received within the past 2 years.	ICES Mental Health and Addictions Program Framework Research Team. Mental Health Dashboard. Last updated October 30, 2024. Available from: https://www.ices.on.ca/dashboards/mental-health-dashboard/

Supplementary table S1. Chronic disease definitions.

Chronic condition	Case definition[1,2,3]	Reference
Stroke	(≥1 hospitalizations) *or* (≥2 outpatient visits, within a 2-year period) *ICD-9:* 362.3, 430, 431, 433, 434, 435, 436 *ICD-10:* I60 (excluding I60.8), I61, I63 (excluding I63.6), I64, G45 (excluding G45.4), H34.0, H34.1 *OHIP dx:* 432, 435, 436	Rosella L, Kornas K, Huang A, Bornbaum C, Henry D, Wodchis WP. Accumulation of chronic conditions at the time of death increased in Ontario from 1994 to 2013. Health Aff (Millwood) 2018;37:464–72.

Supplementary table S2. Comparison of chronic disease weights.

Chronic disease	CAN	CMS (UK)	Charlson index	# of conditions
AMI	0.39	N/A	1	1
Anxiety and mood disorders	0.5	0.5	N/A	1
Asthma	0.13	0.19	N/A	1
Cancer	0.69	1.53	2 or 6	1
Cardiac arrythmia	0.37	1.34	N/A	1
Chronic coronary syndrome	0.55	0.49	1	1
COPD	0.65	1.46	1	1
CHF	1.44	1.18	1	1
Constipation	0.84	1.12	N/A	1
Crohn’s or colitis	0.23	0.21	N/A	1
Dementia	2.11	2.5	1	1
Diabetes	0.48	0.75	1 or 2	1
Epilepsy	0.46	0.92	N/A	1
Hearing loss	0.33	0.09	N/A	1
Hypertension	0.66	0.08	N/A	1
Osteoarthritis	0.38	N/A	N/A	1
Osteoporosis	0.27	N/A	N/A	1
Renal failure	1.19	0.53	3	1
Rheumatoid arthritis	0.33	0.43	1	1
Psychotic disorders	0.56	0.64	N/A	1
Stroke	0.67	0.80	1	1
Substance use disorders	1.77	0.65	N/A	1
Painful condition	N/A	0.92	N/A	1
HIV / AIDS	N/A	N/A	6	N/A
Hemi or Paraplegia	N/A	N/A	2	N/A
Digestive Ulcer	N/A	N/A	1	N/A

CAN: Canadian multimorbidity score; N/A: condition is not included in score.

References

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