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Health care cost of severe obesity and obesity-related comorbidities: A retrospective cohort study from Alberta, Canada

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ABSTRACT

Background: Estimates of health care costs associated with severe obesity, and those attributable to specific health conditions among adults living with severe obesity are needed.
Methods: Administrative data was used to identify adults who previously received a procedure, and had (investigational cohort) or did not have (control cohort) a body mass index $\geq$ 35 kg/m^2. Two-part models were used to estimate the incremental health care cost of severe obesity and related health conditions during a 1-year observation period.
Results: Adjusting for potential confounders, the total health care cost ratio was higher in the investigational (n = 220,190) versus control (n = 1,955,548) cohort (1.32 [95 % CI: 1.32, 1.33]) with a predicted incremental cost of $2221 (95 % CI $2184, $22,265) per person-year; costs were less when obesity-related health conditions were controlled for (1.13 [95 % CI: 1.13, 1.14]; $1097 [95 % CI: $1084, $1110] per person-year). Among those living with severe obesity, incremental costs associated with specific health conditions ranged from $737 (95 % CI: $747, $728) lower (dyslipidemia) to $12,996 (95 % CI: $12,512, $13,634) higher (peripheral vascular disease) per person-year.
Conclusions: Adults living with severe obesity had greater costs than those without, largely driven by obesity-related health conditions. For the Alberta adult population with a severe obesity prevalence of 11 %, severe obesity may account for an estimated additional $453–918 million in health care costs per year. Findings of this study provide rationale for resources and strategies to prevent and manage obesity and its complications.

1. Introduction

Obesity is a complex chronic disease associated with significant impact on health including elevated risk of several chronic health conditions such as diabetes, osteoarthritis, cardiovascular disease, hypertension, and some cancers [1,2]. Globally, the prevalence of obesity (body mass index [BMI] $\geq$ 30 kg/m^2) and severe obesity (BMI $\geq$ 35 kg/m^2) are rising, with severe obesity increasing rapidly; it is estimated that by 2025, the global prevalence of severe obesity will surpass 6 % in men and 9 % in women [3,4]. High-income English-speaking countries appear to represent the largest proportion of the those living with severe obesity at 27 %, followed by 14 % in the Middle East and north Africa [4]. Similar to national estimates for Canada, the prevalence of severe obesity among adults in the province of Alberta is estimated to be 11 % [5].

In addition to the individual health burden, obesity places a substantial economic burden on health care systems, which has been reported to account for 0.7–12.0 % of total health care expenditures for a country [6,7]. Although there is relatively little research on resource use among those living with severe obesity, health care costs appear to increase exponentially as the degree of obesity increases [8,9]. Given this, along with the rising prevalence of severe obesity, a contemporary estimate of the health care costs associated with severe obesity at the population level are needed [10]. This evidence may further inform policies and interventions for weight management strategies. In this study, we evaluated the incremental health care cost of severe obesity

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among adults; to better understand the contribution of obesity-related health conditions to the cost of severe obesity, we included two adjustment sets for potential confounders (adjustment for demographic and other characteristics, and an additional adjustment for obesity-related health conditions). We also assessed costs attributable to specific health conditions in those living with severe obesity, in Alberta.

2. Methods

2.1. Study design

This retrospective cohort study used population-based administrative data and was reported according to STROBE guidelines [11]. This study was approved by the Conjoint Research Ethics Board (Pro00104082, REB20-2152).

2.2. Data sources

The Canadian health care system is publicly funded, providing residents with universal access to all medically necessary hospital and physician services without paying out-of-pocket. In Alberta, the fourth most populous province in Canada with 4.3 million residents, health care is administered under the Alberta Health Care Insurance Plan (AHCIP), of which over 99 % of Albertans participate [12]. Each eligible person is assigned a Personal Health Number that is a unique lifetime identifier; this number was used to link data across data sets. Administrative data from the Discharge Abstract Database (DAD), National Ambulatory Care Reporting System (NACRS), Practitioner Claims, Pharmaceutical Information Network (PIN), and Laboratory Information System (LIS) was linked to the Population Registry, the provincial government health insurance registry that contains demographic information for all Albertans with AHCIP coverage including migraine in and out of the province. DAD and NACRS include demographic, administrative, diagnostic, procedural, and resource intensity weight (RIW) information on people discharged from hospital and facility-based ambulatory care clinics, respectively. Health information management professionals collect this information for the Alberta Health ministry. Practitioner Claims includes patient, provider, and service information such as demographics, speciality, health service and diagnostic codes, date of service, and amount paid to the service provider on fee-for-service, alternative payment plan physician billing, and shadow billing; the Alberta Health ministry collects this information that is submitted by health care providers. Alberta Health is the data custodian of the PIN that contains information on dispensed prescription medications from community pharmacies province wide. LIS includes laboratory test results that are collected by Alberta Health Services (AHS), the single health authority in the province. A comprehensive overview of Canadian administrative health data is provided by Quan et al. [13].

2.3. Study population

In order to determine the incremental health care cost of severe obesity among adults, and those attributable to specific health conditions in those living with severe obesity in Alberta, a study population was required where individuals living with and without severe obesity could be confidently identified. While there are diagnostic codes for obesity, they do not distinguish between the levels of obesity, and have low sensitivity [14]. Therefore, adults who had a select procedure was chosen as the study population, which has been used by others to investigate severe obesity in Alberta [15–17]. In Alberta, BMI modifier codes are used by health care providers for additional payment from the Alberta Health ministry for select surgical, obstetrical, or endoscopic procedures performed on adults who have a documented BMI $\geq$ 35 kg/m^2 (up to 2016) or $\geq$ 40 kg/m^2 (2017 onwards) [18]; claims are subject to audit, and penalties for inappropriate use can be severe. Supplementary Table 1 contains a list of all the select procedures that individuals received during the inclusion period (2012–2019).

Among adults (aged $\geq$ 18-years) that resided in Alberta on April 1, 2019 (index date), the investigational cohort (adults living with severe obesity) included those who: 1) had a select procedure between April 2012 and March 2019 (inclusion period), and 2) had an associated BMI modifier code, and 3) had AHCIP coverage during the inclusion period and $\geq$ 1-year after (observation period) the index date; those who had bariatric surgery during the inclusion or observation periods were excluded.

The control cohort (adults not living with severe obesity) included those who: 1) had a select procedure between April 2012 and March 2019 (inclusion period), and 2) did not have a BMI fee modifier code associated with a select procedure during the inclusion period, and 3) had AHCIP coverage during the inclusion period and $\geq$ 1-year after (observation period) the index date; those who had bariatric surgery during the inclusion or observation periods were excluded.

2.4. Measures

Characteristics determined on the index date included age, sex, urban/rural residence, and socioeconomic status [19,20]. A Charlson Comorbidity Index (CCI) score was determined during the 2-year pre-index period (see Supplementary Table 2 for details) [21]. Fourteen obesity-related health conditions were identified during the inclusion period (asthma, cancer, cardiac disease, cerebrovascular disease, chronic back pain, depression, dyslipidemia, hypertension, insulin resistance, obstructive sleep apnea, osteoarthritis, polycystic ovary syndrome [PCOS], peripheral vascular disease, and type 2 diabetes [1, 22,23]; see Supplementary Table 3 for details).

During the 1-year observation period, health care utilization and costs were determined for hospitalizations, ambulatory care visits, emergency department (ED) visits, and physician visits, as well as community pharmacy prescription medications. Hospitalization, ambulatory care, and ED costs were derived by multiplying the associated RIW with the Canadian Institute for Health Information (CIHI) standardized cost for Alberta in 2019/2020 [24]. RIW is a measure to estimate health care resource use and represents the relative value of resources that a given patient, contingent on diagnostic case-mix, would be expected to consume relative to a standard patient; CIHI provides standardized average costs incurred through the direct care of a standardized patient [25]. Physician visit costs were based on the actual amount paid. Drug costs were calculated using the drug product identification number and quantity dispensed, combined with the drug list price (from Alberta Blue Cross); a 3 % per unit mark-up and a $12.15 dispensing fee was included [26,27]. Costs were reported in 2020 Canadian dollars.

2.5. Statistical analyses

Descriptive statistics were reported as counts and percentages for categorical variables and means and standard deviations (SD) for continuous variables. One- and two-part generalized linear models (GLM) were employed to examine cost differences. In the context of cost outcomes where minimal or absent zero values were present, a GLM with a log-link function and gamma distribution was used to estimate cost ratios along with their corresponding 95 % confidence intervals (CI), which represent multiplicative comparisons in the mean cost per person-year. In instances where cost outcomes had prevalent zero values, a two-part GLM approach was adopted [28]; the first part involved logistic regression to predict the odds of observing a zero cost (corresponding to the odds of not having a cost occurrence or utilization of health care resources), yielding odds ratios that quantify relative differences in odds of zero cost, and the second part, conditional on a non-zero cost, involved a GLM with a log-link function and gamma distribution to predict the positive costs, producing cost ratios along with their corresponding 95 % CI that depict multiplicative comparisons

in the mean incurred costs. The potential confounders of socio-demographic characteristics (age, sex, residence, and socioeconomic status), medical procedure characteristics (type of procedure performed, and whether the procedure was performed during the 6-months before the index date), chronic disease burden (CCI score), and the non-obesity-related comorbidities contained within the CCI were included (partially adjusted model). An additional adjustment set included the 14 obesity-related comorbidities (fully adjusted model).

The overall predicted per person-year adjusted incremental health care cost of severe obesity was estimated by the mean difference between the predicted health care cost of subjects living with severe obesity and corresponding simulated subjects for whom severe obesity was removed and all other covariates retained [29]. This method was also applied to the adjusted incremental health care costs of specific obesity-related health conditions among those living with severe obesity; cost was estimated by the mean difference between the predicted health care cost of subjects living with a specific obesity-related health condition and corresponding simulated subjects for whom the health condition was removed and all other covariates retained. The 95 % CIs were computed from bootstrapping. Analyses were performed using SAS 9.4 software.

3. Results

3.1. Cohort Selection

Among 3,755,572 adult residents of Alberta, 220,190 met criteria for the investigational cohort (people living with severe obesity) and 1,955,548 met criteria for the control cohort (people not living with severe obesity; Supplementary Fig. 1).

3.2. Baseline characteristics

The investigational cohort was more likely to be older (53 [SD 17] versus 50 [SD 17] years), female (71 % versus 57 %), live in rural areas (20 % versus 14 %), experience a higher overall burden of disease (CCI: 0.6 [SD 1.3] versus 0.3 [SD 0.9]), and less socioeconomically well-off (material [14 % versus 20 %] and social [14 % versus 19 %] indices were lower in the most well-off quintile) than the control cohort (Table 1). The investigational cohort was 3-times as likely to have type 2 diabetes (24 % versus 9 %), PCOS (4 % versus 1 %), and asthma (3 % versus 1 %), and 2-times as likely to have hypertension (44 % versus 24 %), osteoarthritis (25 % versus 13 %), cardiac disease (15 % versus 8 %), depression (14 % versus 9 %), chronic back pain (9 % versus 6 %), cancer (9 % versus 5 %), obstructive sleep apnea (4 % versus 2 %), and peripheral vascular disease (2 % versus 1 %) compared with the control cohort (Table 1). The types of procedures received by individuals are listed in Supplementary Table 1.

3.3. Health care resource utilization and cost of severe obesity

The investigational cohort had a higher proportion with at least one hospitalization (13 % versus 7 %), ambulatory care visit (47 % versus 33 %), ED visit (36 % versus 25 %), physician visit (94 % versus 89 %), and medication prescription dispensation (90 % versus 81 %), as well as total mean number of medication dispensations (37 versus 23) compared with the control cohort during the 1-year observation period (Table 2).

Total health care costs were 1.32-times higher (partially adjusted cost ratio: 1.32 [95 % CI: 1.32, 1.33]) in the investigational cohort versus the control cohort, and adult severe obesity had a predicted incremental cost of $2221 (95 % CI $2184, $22,265) per person-year; the higher cost of severe obesity was reduced when obesity-related health conditions were also adjusted for (fully adjusted cost ratio: 1.13 [95 % CI: 1.13, 1.14]; predicted incremental cost: $1097 [95 % CI $1084, $1110] per person-year) (Table 3). Hospitalization, ambulatory care, ED, physician, and prescription drug costs all significantly contributed

Table 1
Baseline subject characteristics.

Characteristics	Investigational cohort (N = 220,190)	Control cohort (N = 1,955,548)
Demographic Characteristics		
Age (years)		
Mean (SD)	53 (17)	50 (18)
Sex		
Female	155,583 (70.7 %)	1,111,909 (56.9 %)
Male	64,607 (29.3 %)	843,638 (43.1 %)
Residence location		
Urban	177,258 (80.5 %)	1,685,823 (86.2 %)
Rural	42,932 (19.5 %)	269,725 (13.8 %)
Socioeconomic Characteristics		
Material deprivation index		
1 (most well off)	29,149 (14.0 %)	378,940 (20.3 %)
2	36,885 (17.7 %)	365,966 (19.6 %)
3	42,333 (20.3 %)	367,367 (19.7 %)
4	48,849 (23.4 %)	385,965 (20.7 %)
5 (most deprived)	51,758 (24.8 %)	368,543 (19.7 %)
Social deprivation index		
1 (most well off)	29,932 (14.3 %)	359,349 (19.3 %)
2	31,359 (15.0 %)	312,398 (16.7 %)
3	42,410 (20.3 %)	360,830 (19.3 %)
4	51,391 (24.6 %)	405,523 (21.7 %)
5 (most deprived)	53,882 (25.8 %)	428,681 (23.0 %)
Clinical Characteristics		
Charlson Comorbidity Index		
Score, mean (SD)	0.6 (1.3)	0.3 (0.9)
Category, n (%)		
0 = no comorbid condition	162,486 (73.8 %)	1,654,034 (84.6 %)
1–2 = mild comorbidity	43,707 (19.9 %)	247,951 (12.7 %)
3–4 = moderate comorbidity	9305 (4.2 %)	36,427 (1.9 %)
≥ 5 = severe comorbidity	4692 (2.1 %)	17,136 (0.9 %)
Obesity-related comorbidities, n (%)		
Hypertension	96,018 (43.6 %)	474,215 (24.3 %)
Dyslipidemia	56,257 (25.6 %)	448,767 (23.0 %)
Osteoarthritis	55,244 (25.1 %)	247,373 (12.7 %)
Type 2 diabetes	53,276 (24.2 %)	178,799 (9.1 %)
Cardiac disease	33,264 (15.1 %)	158,138 (8.1 %)
Depression	31,104 (14.1 %)	168,799 (8.6 %)
Insulin resistance	27,111 (12.3 %)	211,747 (10.8 %)
Chronic back pain	20,524 (9.3 %)	113,106 (5.8 %)
Cancer	20,022 (9.1 %)	104,985 (5.4 %)
Obstructive sleep apnea	9361 (4.3 %)	45,426 (2.3 %)
PCOS (females)	6069 (3.9 %)	14,439 (1.3 %)
Asthma	5686 (2.6 %)	14,841 (0.8 %)
Cerebrovascular disease	5480 (2.5 %)	36,712 (1.9 %)
Peripheral vascular disease	4361 (2.0 %)	22,704 (1.2 %)

Abbreviations: PCOS = polycystic ovarian syndrome; SD = standard deviation.

Table 2
Health care resource utilization and cost during the 1-year observation period.

	Investigational cohort (N = 220,190)	Control cohort (N = 1,955,548)
Had ≥ 1 visit or dispensation, n (%)		
Hospitalization	27,652 (12.6 %)	139,537 (7.1 %)
Ambulatory care	103,300 (46.9 %)	647,903 (33.1 %)
Emergency department	79,417 (36.1 %)	497,862 (25.5 %)
Physician	207,507 (94.2 %)	1,740,066 (89.0 %)
Medication dispensation from a pharmacy	198,597 (90.2 %)	1,584,837 (81.0 %)
Total number of dispensations, mean, median (IQR)	37, 17 (29)	23, 9 (17)

Abbreviations: IQR = interquartile range.

Table 3
Health care cost comparisons between the investigational and control cohorts during the 1-year observation period.

	Odds ratio of zero (95 % CI)	Cost ratio (95 % CI)	Incremental cost* ($CDN, 95 % CI)
Hospitalization			
Unadjusted	0.54 (0.53; 0.54)	1.11 (1.09; 1.12)	2276 (2239, 2313)
Partially adjusted	0.53 (0.53; 0.54)	1.08 (1.07, 1.09)	868 (867, 870)
Fully adjusted	0.53 (0.53; 0.54)	1.04 (1.03, 1.06)	817 (815, 818)
Ambulatory care			
Unadjusted	0.56 (0.56; 0.57)	1.29 (1.28; 1.30)	1024 (1016, 1033)
Partially adjusted	0.56 (0.56; 0.57)	1.12 (1.11, 1.12)	317 (316, 318)
Fully adjusted	0.56 (0.56; 0.57)	1.08 (1.07, 1.09)	293 (292, 294)
Emergency department			
Unadjusted	0.61 (0.60; 0.61)	1.23 (1.22; 1.23)	397 (394, 401)
Partially adjusted	0.60 (0.60; 0.61)	1.10 (1.09, 1.11)	131 (131, 132)
Fully adjusted	0.60 (0.60; 0.61)	1.03 (1.03, 1.04)	114 (113, 114)
Physician visit			
Unadjusted	NA	1.55 (1.55; 1.56)	1934 (1926, 1942)
Partially adjusted	NA	1.22 (1.21, 1.23)	368 (366, 370)
Fully adjusted	NA	1.06 (1.06, 1.07)	122 (122, 123)
Prescription drugs			
Unadjusted	NA	1.80 (1.79; 1.81)	1648 (1641, 1655)
Partially adjusted	NA	1.46 (1.46, 1.47)	685 (676, 695)
Fully adjusted	NA	1.19 (1.18, 1.19)	405 (399, 409)
Total cost			
Unadjusted	NA	1.77 (1.76; 1.78)	7280 (7249, 7310)
Partially adjusted	NA	1.32 (1.32, 1.33)	2221 (2184, 2265)
Fully adjusted	NA	1.13 (1.13, 1.14)	1097 (1084, 1110)

Abbreviations: CDN = Canadian; CI = confidence interval; NA = not applicable.
* Adjusted incremental costs were calculated as the mean difference between the predicted cost of a subject living with severe obesity and the predicted cost of a corresponding subject simulating removal of severe obesity. The odds ratio of zero cost and the cost ratio from the two-part model was used to estimate hospitalization, ambulatory care, and emergency department cost outcomes, as these health resources had > 50 % zero values. All differences were statistically significant at $p < 0.05$.

to the higher cost of severe obesity (Table 3). Applying these costs to the population level, it is estimated that $918 million per year in health care costs are attributable to severe obesity that includes obesity-related health conditions, and $453 million per year when obesity-related health conditions are controlled for (calculation: 11 % of 3,755,572 adult residents of Alberta living with severe obesity × $2221 or $1097 = $918 or $453 million; [5]).

3.4. Health care cost of obesity-related health conditions

Table 4 details total health care cost comparisons among those in the investigational cohort who had and did not have a specific obesity-related health condition. In fully adjusted models, each specific obesity-related health condition had a statistically higher total health cost that ranged from $112 (95 % CI $111, $114; insulin resistance) to $12,996 (95 % CI $12,512, $13,634; peripheral vascular disease) per person-year, except dyslipidemia which was lower (Table 4).

Fig. 1 illustrates the population level total health care costs of each specific obesity-related health condition among those living with severe obesity; the incremental cost of each condition was multiplied by the proportion of subjects within the investigational cohort who had the specific comorbidity (see Table 1), and applied to the adult population of Alberta living with severe obesity. Hypertension, type 2 diabetes, cardiac disease, and osteoarthritis were the costliest comorbidities, ranging between $302 and $387 million each per year.

4. Discussion

In this contemporary, population-based study, we found that adults living with severe obesity had higher use of health care resources, medications, and total health care costs than those not living with severe obesity. When cost estimates included obesity-related health conditions, adult severe obesity was associated with a 1.32-times higher total health cost and a predicted incremental cost of $2 221 per person-year (partially adjusted model); additionally controlling for obesity-related health conditions (which may underestimate cost associated with obesity) reduced the cost of adult severe obesity to a 1.13-times higher cost and a predicted incremental cost of $1097 per person-year (fully adjusted model). If these findings hold for the Alberta population, severe obesity may account for an estimated additional $453–918 million in health care costs per year for this province. Among adults living with severe obesity, the presence of specific obesity-related health conditions was associated with greater per-person annual costs that ranged from $112 (insulin resistance) to $12,996 (peripheral vascular disease) higher than those who did not have the specific condition, except dyslipidemia. At the population level, hypertension was the largest cost driver at an estimated $387 million per year among adults living with severe obesity in Alberta.

There is general consensus that obesity places a significant financial burden on the health care system, although the estimated magnitude of this incremental cost can vary considerably. One of the most significant drivers of variability in obesity cost estimates has been found to be adjustments for obesity-related health conditions [30,31]. Using data from the USA 2008–2010 Medical Expenditure Panel Survey, Kim et al. found that while controlling for socio-demographic and other (census region, insurance status) confounding factors had a modest reduction in the incremental cost of adult obesity, also controlling for obesity-related health conditions reduced the incremental cost of obesity to between one-fourth and one-seventh the original estimate [30]. Similarly, in this study, the total incremental health care cost of severe obesity reduced to one-third the unadjusted estimate when socio-demographic, clinical, and procedure characteristics were controlled for (partially adjusted model), and reduced to one-seventh the unadjusted estimate when obesity-related health conditions were also controlled for (fully adjusted model), reflecting the substantial contribution of obesity-related health conditions to the cost of severe obesity. As the precise attribution of obesity-related conditions is not known in this study, the attributable cost of severe obesity likely lies in between the estimated cost of the partially and fully adjusted model.

Few studies have examined the economic burden of individual obesity-related health conditions. Li et al. conducted a population-based study using administrative health data from the USA that included 56,895 adults, among whom 40 % had a BMI $\geq$ 30 kg/m^2, and assessed the incremental health care costs of 21 obesity-related health conditions [32]. Adjusting for demographics and the other obesity-related health conditions, cardiovascular disease, osteoarthritis, and gallbladder disease were found to have the largest cost ratios and incremental health care costs per person. At the population level, the annual incremental cost of hypertension, dyslipidemia, and osteoarthritis had the highest economic burden, which the authors attributed to most likely being driven by the high prevalence of these conditions; these conditions were

Table 4
Total health care cost comparison between those with and without a specific obesity-related health condition, among the investigational cohort.

Health condition	Cost ratio (95 % CI)	Incremental cost* ($CDN, 95 % CI)	Health condition	Cost ratio (95 % CI)	Incremental cost* ($CDN, 95 % CI)
Dyslipidemia			Osteoarthritis		
Unadjusted	1.28 (1.26; 1.29)	1878 (1799, 1957)	Unadjusted	1.99 (1.97; 2.01)	5787 (5686, 5888)
Partially adjusted	0.99 (0.98; 1.00)	-78 (− 79, − 77)	Partially adjusted	1.36 (1.35; 1.38)	3569 (3515, 3624)
Fully adjusted	0.93 (0.92; 0.94)	-737 (− 747, − 728)	Fully adjusted	1.28 (1.26; 1.29)	2909 (2870, 2946)
Insulin resistance			Type 2 diabetes		
Unadjusted	1.33 (1.31; 1.34)	1712 (1625, 1800)	Unadjusted	2.43 (2.41; 2.46)	7517 (7405, 7629)
Partially adjusted	1.04 (1.03; 1.06)	297 (294, 301)	Partially adjusted	1.38 (1.37; 1.40)	4012 (3959, 4073)
Fully adjusted	1.02 (1.01; 1.03)	112 (111, 114)	Fully adjusted	1.33 (1.32; 1.35)	3674 (3628, 3727)
PCOS (females)			Chronic back pain		
Unadjusted	0.76 (0.74; 0.78)	-1579 (− 1709, − 1450)	Unadjusted	1.87 (1.84; 1.90)	5858 (5683, 6032)
Partially adjusted	1.12 (1.09; 1.15)	534 (518, 548)	Partially adjusted	1.55 (1.52; 1.57)	5397 (5223, 5540)
Fully adjusted	1.08 (1.05; 1.10)	365 (354, 374)	Fully adjusted	1.40 (1.38; 1.42)	4375 (4279, 4459)
Cancer			Cardiac disease		
Unadjusted	2.01 (1.99; 2.04)	6764 (6576, 6952)	Unadjusted	2.85 (2.82; 2.89)	10,538 (10,361, 10,714)
Partially adjusted	0.89 (0.88; 0.91)	-2541 (− 2634, − 2463)	Partially adjusted	1.48 (1.46; 1.50)	6396 (6299, 6501)
Fully adjusted	1.11 (1.09; 1.13)	1641 (1602, 1679)	Fully adjusted	1.41 (1.39; 1.43)	5649 (5577, 5727)
Cerebrovascular disease			Asthma		
Unadjusted	2.44 (2.38; 2.51)	10,144 (9688, 10,600)	Unadjusted	1.98 (1.93; 2.03)	6940 (6574, 7306)
Partially adjusted	1.20 (1.17; 1.24)	4337 (4069, 4629)	Partially adjusted	1.60 (1.55; 1.64)	6009 (5748, 6284)
Fully adjusted	1.13 (1.10; 1.16)	2823 (2670, 2968)	Fully adjusted	1.45 (1.41; 1.49)	5032 (4839, 5231)
Hypertension			Depression		
Unadjusted	2.41 (2.39; 2.43)	6364 (6291, 6437)	Unadjusted	1.59 (1.57; 1.61)	3942 (3819, 4064)
Partially adjusted	1.39 (1.37; 1.40)	3329 (3279, 3376)	Partially adjusted	1.64 (1.62; 1.66)	4886 (4748, 5013)
Fully adjusted	1.22 (1.20; 1.23)	2146 (2117, 2172)	Fully adjusted	1.53 (1.52; 1.55)	4397 (4296, 4485)
Obstructive sleep apnea			Peripheral vascular disease		
Unadjusted	2.27 (2.22; 2.32)	8763 (8445, 9082)	Unadjusted	3.94 (3.83; 4.06)	20,240 (19,435, 21,045)
Partially adjusted	1.43 (1.40; 1.46)	6331 (6049, 6593)	Partially adjusted	1.58 (1.53; 1.63)	13,698 (13,043, 14,464)
Fully adjusted	1.23 (1.20; 1.25)	3774 (3667, 3872)	Fully adjusted	1.56 (1.51; 1.61)	12,996 (12,512, 13,634)

Abbreviations: CDN = Canadian; CI = confidence interval; PCOS = polycystic ovarian syndrome.
* Adjusted incremental costs were calculated as the mean difference between the predicted cost of a subject living with severe obesity who had a specific health condition and the predicted cost of a corresponding subject living with severe obesity simulating removal of the specific health condition.

also the costliest comorbidities among those with a BMI $\geq$ 30 kg/m^2 [32]. In the current study, the high population level incremental costs of hypertension, type 2 diabetes, and osteoarthritis were driven by the large proportion of adults living with severe obesity who had these conditions, while the incremental cost of cardiac disease was driven to a greater extent by the high costs of this condition.

Regarding the specific obesity-related health conditions assessed in this study among those living with severe obesity, dyslipidemia was found to incur a lower incremental cost. Based on national surveys from the USA, it has been estimated that approximately 63–68 % of adults with a BMI $\geq$ 35 kg/m^2 have dyslipidemia [33,34]. Considering that only 26 % of adults living with severe obesity were identified as having dyslipidemia in this study and the unadjusted incremental cost ratio of dyslipidemia was 1.3-times higher for those with the condition versus without, a finding similar to Li et al. [32], it may be possible that this condition was unrecognized in a number of adults living with severe obesity, and therefore influenced results.

This study has many strengths but also a number of limitations. The study population was limited to adult residents of Alberta who underwent a select procedure before the observation period, and therefore may not be representative of the entire adult general population of Alberta. Administrative data was used as opposed to medical records, and therefore there is a potential for misclassification of study measures including individuals in the control cohort who may have been living with severe obesity, but a BMI modifier code was not applied. Although unlikely, this may have resulted in more conservative cost estimates. This study design has been applied by others [15–17], and it is assumed that BMI classification was maintained between the date of identification and the 1-year observation period. In Alberta, administrative data is collected separately for health care services and treatments that occur at cancer centers, and does not contain costing information; therefore, incremental costs associated with cancer are likely underestimated. While numerous potential confounders were controlled for in this study, the possibility of residual confounding due to unobserved factors may still be present in the adjusted cost estimations.

This study provided a contemporary population level estimate of the health care costs associated with severe obesity, and specific obesity-related health conditions among those living with severe obesity in Alberta. Adults living with severe obesity used health care resources to a greater extent and incurred higher incremental costs compared to those not living with severe obesity, which may represent an estimated additional $453–918 million per year in provincial health care costs related to BMI-defined obesity and related health conditions. Among those living with severe obesity, hypertension is the costliest health condition at the population level, driven by its high prevalence. Canadian clinical practice guidelines for obesity in adults highlights lack of access to obesity treatments is a contributing factor to the rising prevalence of severe obesity in Canada [10]; to this end, findings of this study provide additional rationale for investment in tools, strategies, and interventions that are effective in preventing and treating obesity and its complications.

Ethical Statement

This study was approved by the Conjoint Research Ethics Board (Pro00104082, REB20-2152). This is a study of administrative data without any intervention. No study participants were placed at risk as a result of this study. Informed consent was not required.

CRediT authorship contribution statement

HL, AG, KM, and SK made substantial contributions to study conception and design, HL and AG acquired and analyzed the data, and all authors contributed to interpretation of data for the work; KM initially drafted the work and all authors revised it critically for important intellectual content; all authors approved the final version and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are

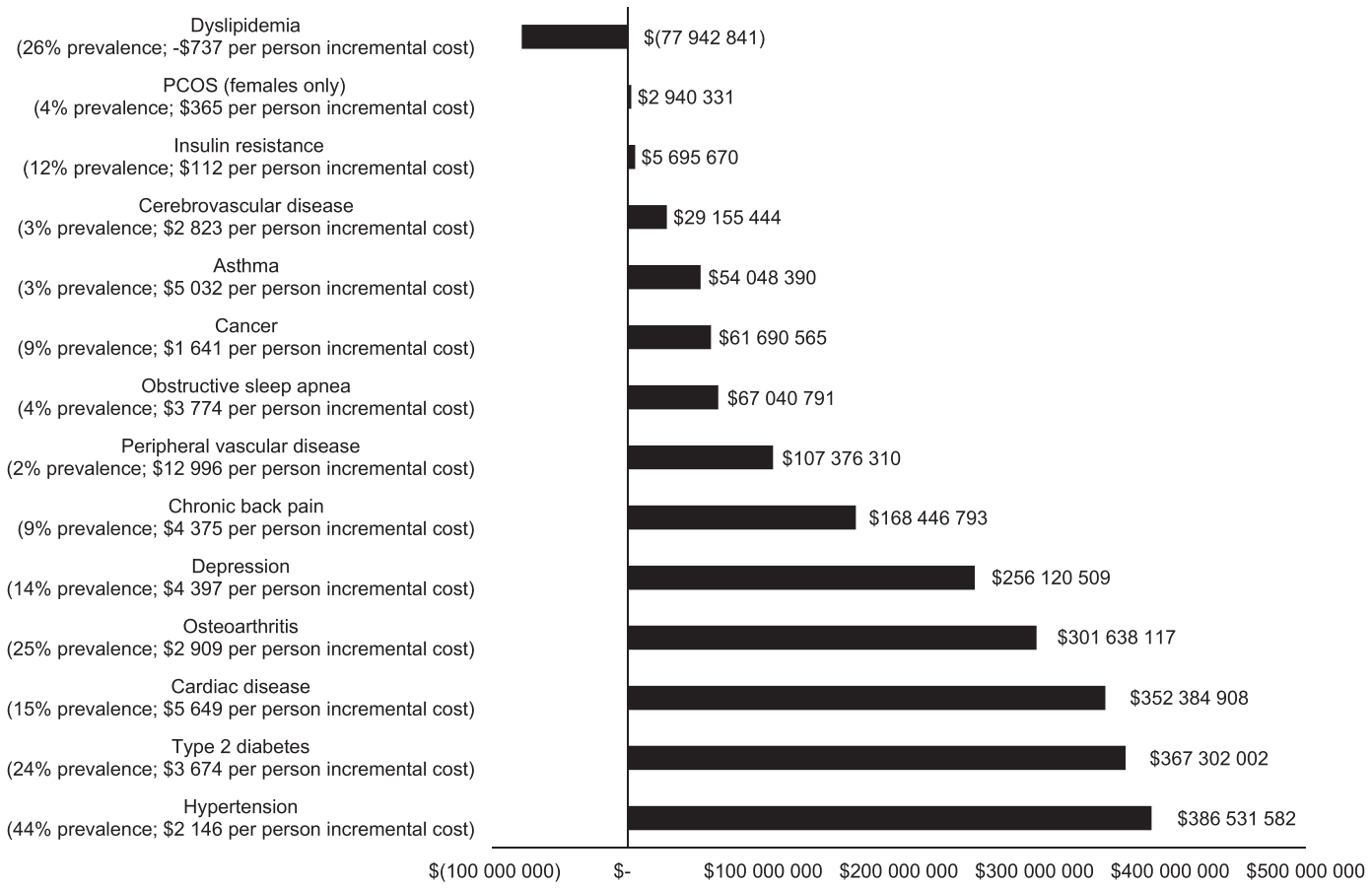

Fig. 1. Population level total health care costs of specific obesity-related health conditions among those living with severe obesity. Abbreviations: PCOS = polycystic ovarian syndrome.

appropriately investigated and resolved.

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Author agreement

The authors agree that this study adheres to the STROBE guidelines. All authors have abided by the statement of ethical standards for manuscripts submitted to the Obesity Research & Clinical Practice.

Declaration of Competing Interest

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: HL, KM, TW, and SK are members (AG was a member) of the Alberta Real World Evidence Consortium, and academic entity that conducts research including investigator-initiated industry-funded studies. No other conflict of interest was declared. All authors of this study had complete autonomy over the content and submission of the manuscript, as well as the design and execution of the study.

Data Availability Statement

The datasets analyzed during the current study are not publicly available due to contractual arrangements with the data custodians (provincial health ministry and Alberta Health Services).

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.orcp.2023.09.006.

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