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Original quantitative research

Gender differences in the longitudinal association between multilevel latent classes of chronic disease risk behaviours and body mass index in adolescents

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Abstract

Introduction: Few studies have assessed the relationship between chronic disease risk behaviours and body mass index (BMI) in a longitudinal, sex/gender-specific context. This study used gender-specific analyses to assess the extent to which chronic disease risk behaviour latent classes are associated with BMI and weight status at follow-up.

Methods: Longitudinal data from 4510 students in Grades 9 to 12, tracked from 2013–2015, who participated in the COMPASS study were used to assess gender differences in the lagged association between previously determined latent classes (of physical activity and substance use) with BMI using multilevel mixed-effects models. Our multilevel regression models assessed the association between two latent classes, active experimenters and inactive non-using youth, with BMI when stratified by gender.

Results: Male inactive non-substance-using youth were associated with a 0.29 higher continuous BMI (95% CI: 0.057, 0.53) and odds of overweight/obesity increased by 72% (OR = 1.72, 95% CI: 1.2, 2.4) for binary BMI at follow-up relative to active youth who experiment with substance use. No significant associations were detected in females.

Conclusion: Over time, physical activity has a protective role on BMI in male youth. Both substance use and physical inactivity should be addressed in obesity prevention efforts. Gender stratification in analyses is also important since females and males have different contributing factors to increases in BMI.

Keywords: *chronic disease risk behaviours, substance use, physical activity, sex, gender, BMI, obesity, overweight, adiposity*

Highlights

- Approximately 20% of youth who were overweight/obese were in the normal weight body mass index (BMI) category 1 year later.
- Male inactive non-substance users had increases in BMI and increases in the odds of becoming overweight/obese relative to their active substance-using peers. No associations were identified in females.
- Physical activity seems to play a role in males in prospectively maintaining BMI despite their engagement with substance use.

Introduction

Overweight and obesity are escalating in youth: 27% of Canadian children were classified as overweight or obese in 2013.[1] Childhood obesity tracks into adulthood, increasing the risk of adult chronic diseases.[2,3] That body mass index (BMI) decreases in youth over time (in males more than in females), but not in adults, highlights the importance of prevention efforts directed at this age group.[1,4,5]

Despite public health prevention and intervention efforts, BMI is increasing in certain populations, including in Canadian youth.[5,6] Overweight/obesity have many determining factors, of which chronic disease risk behaviours (CDRB; e.g. physical inactivity, binge drinking) are major contributors.[7,8] Laxer et al.[6] used longitudinal data (2012–2014) from the Cohort Study on Obesity, Marijuana Use, Physical Activity, Alcohol Use, Smoking and Sedentary Behaviour (COMPASS) to assess the effect of 15 CDRB (including physical inactivity, dietary choices and sedentary and substance use behaviours) at baseline (via latent classes) on BMI at concurrent years, while controlling for gender. The authors found that BMI increased by an average of 0.61 units per year; however, the researchers were unable to identify a specific latent class that had higher risk of increasing BMI.

Devis-Devis et al.[4] and Jackson & Cunningham[9] did not find an association between CDRB latent classes and obesity, and recommended further investigation.[4] A limitation of these two studies is that they only included physical activity, sedentary behaviours and diet,[4,10] despite evidence that substance users (i.e. smokers and marijuana users) are most likely to have

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overweight/obesity relative to their non-substance-using counterparts.[11-13]

Another notable shortcoming of previous research has been the lack of assessment of the role of sex/gender in the association between CDRB and obesity.[6,9,14,15] For instance, Laxer et al. reported that males were associated with a higher increase in BMI, but did not conduct sex/gender-specific modelling.[6] Published studies have demonstrated sex/gender differences in BMI[16,17] and in CDRB engagement—including physical inactivity and substance use[17,18], indicating that sex/gender-specific models are warranted. Research has also found that physical inactivity and substance use play roles in youth overweight and obesity,[14,15,17,19,20] showing the importance of incorporating substance use, as well as sex/gender-stratified analyses, into research of obesity in youth.

Given the notable gaps in obesity literature, Hammami et al.[17] identified latent classes of CDRB (physical inactivity, binge drinking, marijuana use and tobacco smoking) in 2013–2015 and regressed BMI onto these classes (in repeated cross-sectional analyses) in youth in Ontario, Canada, participating in COMPASS. The authors found that latent classes with inactivity and substance use in females were associated with higher odds of overweight/obesity relative to active and non-substance-using females; in contrast, activity and experimenting with substance use in males were associated with higher odds of overweight/obesity relative to inactive non-substance-using males.[17]

However, whether individuals in these latent classes had higher BMIs, for both sexes/genders, relative to their counterparts at follow-up remains unknown. This information is crucial for obesity and substance use prevention programs because CDRB are modifiable, and addressing them while youth are at school can help mitigate the impact of factors associated with high/increasing BMI. As such, the aim of this study was to investigate the prospective association of CDRB latent classes, namely physical inactivity, binge drinking, marijuana use and tobacco smoking, with BMI, while accounting for gender, among participants in COMPASS in Ontario, Canada.

Methods

COMPASS is a large longitudinal study (2012–2021) collecting behaviour and outcome data from secondary school students in Canada. Further information on COMPASS (http://www.compass.uwaterloo.ca) is available elsewhere.[21]

This study used three waves of COMPASS data from Ontario, Canada. Wave 1 was collected in the 2013/14 school year, Wave 2 in the 2014/15 school year and Wave 3 in the 2015/16 school year. Consistent with earlier research,[6,17] we chose to focus our attention on Ontario data as these constitute 92% of the observations for these waves of COMPASS data.

Participants

A total of 41 734 youth in Grades 9, 10, 11 or 12 responded to the student questionnaire in Wave 1, 39 013 responded in Wave 2 and 37 106 responded in Wave 3. Most of the students who did not respond (20.9%, 21.6% and 20.1% in Waves 1, 2 and 3, respectively) were absent from school the day the questionnaire was administered. Students were recruited from schools that permit active-information, passive-consent protocols (n = 79, 78 and 72 in Waves 1, 2 and 3, respectively). In addition to the approval of the schools and school boards, the University of Waterloo Office of Research Ethics approved all procedures. Passive consent was obtained from participants.

Schools that participated in at least two of the three waves (n = 70 in each wave) were included in this study. Youth who responded to the student questionnaire more than once (n = 6594) were included in the study.

Measures

Body mass index (dependent variable)

We calculated BMI from the self-reported height and weight measures. We used the World Health Organization sex-specific BMI-for-age cut-off values corresponding to the age of our sample.[22] The measures used to determine BMI in COMPASS participants have previously been validated (intraclass correlation coefficient [ICC] = 0.84).[23]

BMI calculated at each time-point ranged from 10.0 to 49.9 kg/m^2, which suggests the presence of outliers. On removal of outliers at the 1% and 99% ends of the range, BMI was 15.5 to 35.9. BMI was used as a continuous and as a binary outcome (weight status) for comparative purposes. We used weight status based on BMI cut-offs (overweight/obese versus normal weight) because youth classified as overweight or obese have similar risks of future chronic diseases[24]; in addition, doing so is consistent with previously published studies.[15,17,25]

Chronic disease risk behaviours (independent variables)

The CDRB measures and multilevel latent class analysis procedure are briefly described below. (For more information, see Hammami et al.[17])

Physical activity

We described youth as being physically active if they were in compliance with the *Canadian 24-Hour Movement Guidelines for Children and Youth*.[17,26]

Substance use behaviours

To identify current cigarette smokers, the questionnaire included questions asking (1) if respondents had ever smoked 100 or more whole cigarettes in their life; and (2) on how many days respondents had smoked one or more cigarettes in the past 30 days. Students who answered “yes” to the first question, and reported any smoking in the previous 30 days were identified as current smokers.[17,27]

To identify binge-drinking behaviour, respondents were asked how often they had had five or more drinks of alcohol on one occasion during the past 12 months. Current binge drinkers were identified as those who had had five or more drinks at least once in the last month.[17,28,29]

Respondents were asked how often they used marijuana or cannabis during the past 12 months. They were classified as current marijuana users if they had used marijuana in the last month.[17,28,29]

Chronic disease risk behaviour (CDRB) latent classes

We previously conducted multilevel latent class analysis using gender-specific models for Waves 1–3 of the data in this study to independently assess the consistency of the CDRB profiles identified over time.[17] The findings suggested either two latent classes, active experimenters and inactive non-users, or three latent classes, active experimenters, inactive non-users and inactive substance users.

To ensure that the classes studied over time (in terms of their association with

BMI) were comparable, we assumed that the classes were fixed in number and type.[30] Since all waves in our study had at least two latent classes, we performed our longitudinal analyses with a parsimonious model of two student latent classes; in addition, this parsimony makes for easier interpretation and communication of findings.

Other variables: ethnicity and gender

We identified ethnicity based on responses to the question "How would you describe yourself?" in the student questionnaire. Options for answers were "White," "Black," "Asian," "Aboriginal (First Nations, Métis, Inuit)," "Latin American/Hispanic" or "Other." We grouped all the non-White ethnicities as they constituted only about 25% of the sample. In these analyses ethnicity is only used as a control variable.

We identified gender based on the answer to the question "Are you female or male?" with the options "female" and "male" as answers.

Statistical analyses

For variable descriptive statistics, we calculated gender-specific frequencies and percentages for categorical variables of interest and reported means and standard deviations for continuous variables. All analyses in this study used statistical package SAS version 9.4 (SAS Institute Inc., Cary, NC, USA) with a threshold of significance $p < .05$.

Bivariate exploratory analysis was conducted using McNemar test to assess the degree to which youth changed weight status categories and latent classes (i.e. transitions) across consecutive waves.

We used gender-stratified mixed-effects regression models to assess the longitudinal association between (lagged) CDRB latent classes and BMI (at follow-up). These models considered the outcome BMI in two ways: as continuous BMI and as binary BMI (overweight/obese versus normal weight). All mixed models adjusted for the following predictors while accounting for the hierarchical structure of the data: BMI (in the previous wave), ethnicity (at baseline), grade (at current wave) and year.

All mixed-effects regression models restricted analysis to monotone patterns of missingness in the outcome variable via maximum likelihood, based on the assumption that the data are "missing at random."[31] Altogether 4510 youth participated in at least two student questionnaires across the three waves (with a monotone pattern of missing BMI) and were included in the analyses.

Results

Study participants

For each of the three Waves, females accounted for 51.1% of secondary school students responding (Table 1). The mean BMI at Wave 1 was 21.0 in females and 21.6 in males (classified as normal weight). Estimates were similar at Waves 2 (females, 21.6; males, 22.4) and 3 (females, 21.9; males, 22.9).

More than half of the female youth reported a normal BMI (55.2%, 55.0% and 55.2% for Waves 1, 2 and 3, respectively). This was higher than the proportion of males reporting a normal BMI (44.8%, 45.0% and 44.8%, respectively). In tandem, males reported higher overweight/obesity rates (61.7%, 61.1% and 61.5%, respectively) than their female

TABLE 1
Summary statistics for longitudinal outcomes and covariates, by gender, Grade 9–12 secondary school students, COMPASS (Ontario, Canada)

Demographics	Study participants, % (n)[a]					
	Wave 1		Wave 2		Wave 3	
	Females	Males	Females	Males	Females	Males
Gender distribution	51.1 (2307)	48.9 (2203)	51.1 (2307)	48.9 (2203)	51.1 (2307)	48.9 (2203)
Ethnicity						
White	51.5 (1826)	48.5 (1721)	–	–	–	–
Non-White	50.2 (474)	49.8 (470)	–	–	–	–
Grade						
9	50.7 (1551)	49.3 (1505)	–	–	–	–
10	53.0 (724)	47.0 (643)	50.7 (1541)	49.3 (1500)	–	–
11	36.8 (32)	63.2 (55)	53.1 (728)	46.9 (643)	50.7 (1532)	49.3 (1488)
12	–	–	37.4 (31)	62.6 (52)	52.3 (747)	47.7 (682)
Weight status (binary BMI)[b]						
Normal	55.2 (1896)	44.8 (1541)	55.0 (1782)	45.0 (1457)	55.2 (1642)	44.8 (1334)
Overweight/obese	38.3 (411)	61.7 (662)	39.9 (413)	61.1 (648)	38.5 (362)	61.5 (578)
Continuous BMI (SD)	21.0 (3.1)	21.6 (3.4)	21.6 (3.2)	22.4 (3.5)	21.9 (3.2)	22.9 (3.5)
Latent classes						
Active experimenters	59.0 (128)	41.0 (89)	49.9 (253)	50.1 (254)	46.0 (354)	54.0 (415)
Inactive non-users	50.8 (2179)	49.2 (2114)	51.3 (2054)	48.7 (1949)	52.2 (1953)	47.8 (1788)

Abbreviations: BMI, body mass index; COMPASS, Cohort Study on Obesity, Marijuana Use, Physical Activity, Alcohol Use, Smoking and Sedentary Behaviour; SD, standard deviation.

[a] Percentages and sample size are reported for categorical variables; mean and standard deviation are reported for continuous variables.

[b] BMI weight status categorizations were age- and sex-specific as reported from the World Health Organization (WHO) growth charts.[22]

counterparts (38.3%, 39.9% and 38.5%, respectively).

Weight status transitions

Most youth who were classified as having a normal weight remained in this category at follow-up (Wave 1 to 2: females = 92.8%, males = 89.5%; Wave 2 to 3: females = 95.0%, males = 90.3%) (Table 2). Youth with overweight/obesity also tended to remain in the same category across consecutive waves (Wave 1 to 2: females = 75.1%, males = 78.4%; Wave 2 to 3: females = 78.4%, males = 77.7%).

A lower proportion of females than of males reported transitioning from a normal weight to overweight/obesity at follow-up (Wave 1 to 2: females = 7.2%, males = 10.5%; Wave 2 to 3: females = 5.0%, males = 9.7%). A greater proportion of female youth transitioned from overweight/obesity to normal weight at follow-up (Wave 1 to 2: females = 24.9%, males = 21.6%; Wave 2 to 3: females = 21.6%, males = 22.3%). These transitions were found to be significant only in females for Wave 1 to 2.

Latent class transitions

Most active experimenters were the same at follow-up (Waves 1 to 2: females = 71.9%, males = 71.9%; Waves 2 to 3: females = 70.7%, males = 70.9%) (Table 3). Similarly, inactive non-users remained largely non-using at follow-up (Waves 1 to 2: females = 92.6%, males = 91.0%; Waves 2 to 3: females = 91.5%, males = 87.9%).

Transition from active experimenting to inactive non-user status occurred at higher rates than the reverse, that is, from inactive non-using to active experimenting status (Wave 1 to 2: females = 28.1%, males = 28.1%; Waves 2 to 3: females = 29.3%, males = 29.1%). A significant McNemar chi-square test statistic ($p < .0001$) suggests that there are statistically significant transitions in youth's CDRB latent classes across a 1-year period.

Longitudinal regression analyses

Male inactive non-users in the previous wave were associated with an average increase of 0.29 in continuous BMI at follow-up relative to their active experimenter counterparts (95% confidence interval [CI]: 0.057, 0.53) (Table 4). When weight status was used as an outcome, inactive non-using males were associated with 72% higher odds of overweight/obesity relative to their active experimenter counterparts (OR = 1.72, 95% CI: 1.2, 2.4). No significant associations were identified in females.

TABLE 2
Transitions in weight status across consecutives waves (Waves 1 to 2 and 2 to 3), by gender, Grade 9–12 secondary school students, COMPASS (Ontario, Canada)

	Population	Binary BMI status[a], % (n) Normal	Overweight/obese	McNemar chi-square
		Wave 2		
Wave 1	**Females**			
	Normal	92.8 (1688)	7.2 (130)	5.78*
	Overweight/ Obese	24.9 (94)	75.1 (283)	
	Males			
	Normal	89.5 (1321)	10.5 (155)	1.24
	Overweight/ Obese	21.6 (136)	78.4 (493)	
		Wave 3		
Wave 2	**Females**			
	Normal	95.0 (1565)	5.0 (82)	0.16
	Overweight/ Obese	21.6 (77)	78.4 (280)	
	Males			
	Normal	90.3 (1205)	9.7 (129)	0
	Overweight/ Obese	22.3 (129)	77.7 (449)	

Abbreviations: BMI, body mass index; COMPASS, Cohort Study on Obesity, Marijuana Use, Physical Activity, Alcohol Use, Smoking and Sedentary Behaviour.

[a] BMI weight status categorizations were age- and sex-specific as reported from the World Health Organization (WHO) growth charts.[22]

* $p < .05$.

Discussion

Building on earlier research,[17] we conducted a longitudinal analysis assessing for gender differences in the association of CDRB with BMI at follow-up. Our assessment shows that, at follow-up, BMI was higher by 0.29 in inactive non-using males than among active experimenters, with no such significant association in females. In addition, inactive non-using males were associated with 72% higher odds of overweight/obesity relative to their more active counterparts who experiment with substances.

Our findings emphasize the importance of stratified analyses that assess the association between CDRB and longitudinal BMI because the results of cross-sectional analyses in our earlier research[17] are not likely to be consistent with findings from longitudinal analyses.

Substance use is associated with higher prevalence and incidence of obesity.[12,14,19,32] Our findings can be partially explained by the difference in physical activity across the two classes. Physical activity was found to be protective against obesity in male but not female youth in the United States.[33]

Physical activity is not the sole behaviour that contributes to differences in overweight/obesity. Research shows that unhealthy CDRB collectively contribute to higher BMI in youth. Low physical activity does not occur in isolation; it is usually associated with poor dietary intake and sedentary behaviour, and how research is conducted should reflect that.[34-37]

The problem behaviour theory (1977) explains that youth who engage in one problem behaviour are at a higher risk of other problem behaviours due to the shared meanings and the social influences surrounding the behaviours.[38] Research indicates that behaviour change (positive or negative) is more effective when the behaviours are addressed simultaneously rather than each in isolation.[39] Furthermore, peer effects are reportedly associated with differences in diet, exercise and BMI.[37,40] Recent findings from Europe also suggest that active experimenters likely have experimenter friends who tend to be

TABLE 3
Transitions in latent classes across consecutive waves (Waves 1 to 2 and 2 to 3), by gender, Grade 9–12 secondary school students, COMPASS (Ontario, Canada)

		Chronic disease risk behaviour latent classes, % (n)		McNemar chi-square
		Active experimenters	Inactive non-users	
		Wave 2		
Wave 1	Females			
	Active experimenters	71.9 (92)	28.1 (36)	79.3***
	Inactive non-users	7.4 (161)	92.6 (2018)	
	Males			
	Active experimenters	71.9 (64)	28.1 (25)	126.6***
	Inactive non-users	9.0 (190)	91.0 (1924)	
		Wave 3		
Wave 2	Females			
	Active experimenters	70.7 (179)	29.3 (74)	41.0***
	Inactive non-users	8.5 (175)	91.5 (1879)	
	Males			
	Active experimenters	70.9 (180)	29.1 (74)	83.9***
	Inactive non-users	12.1 (235)	87.9 (1714)	

Abbreviation: COMPASS, Cohort Study on Obesity, Marijuana Use, Physical Activity, Alcohol Use, Smoking and Sedentary Behaviour.
***p <.0001.

physically active in their free time. It is reported that athletes' perceived social norms and increased exposure to alcohol through alcohol advertising during sporting events play a prominent role in their higher drinking habits relative to their peers.[41,42] Similarly, inactive non-using youth likely have non-using friends with sedentary pastimes (e.g. TV viewing, video games).[37]

Consistent with earlier research,[5,6] our analyses indicate that there are annual increases in BMI across genders but that the predictors of the annual increase differ. Physical activity and substance use are not likely predictors of increasing BMI in females. Studies show that adult women have healthier dietary patterns than adult men.[43] Nevertheless, a study of adults in Scotland, England and Northern Ireland reported that variance in BMI was explained by physical activity (by 10.3%) and dieting behaviours (by 10.3%), while healthy eating explained only 1.6% of the variance.[43]

TABLE 4
Adjusted estimates from mixed-effects models[a] that regressed BMI onto lagged latent classes, by gender, Grade 9–12 secondary school students, COMPASS (Ontario, Canada)

Latent class in previous wave	Regression coefficients (95% CI)[b]	OR (95% CI)[c]
Females		
	Model 1	Model 2
Active experimenter (Ref.)		
Inactive non-user	−0.0087 (−0.20, 0.19)	0.85 (0.55, 1.32)
Males		
	Model 3	Model 4
Active experimenter (Ref.)		
Inactive non-user	0.29* (0.057, 0.53)	1.72** (1.2, 2.4)

Abbreviations: BMI, body mass index; CI, confidence interval; COMPASS, Cohort Study on Obesity, Marijuana Use, Physical Activity, Alcohol Use, Smoking and Sedentary Behaviour; OR, odds ratio; Ref.: reference.
[a] All models adjusted for BMI (in the previous wave), ethnicity (at follow-up), grade (at follow-up) and year.
[b] Regression coefficient (95% CI) from the linear regression, with continuous BMI as an outcome.
[c] Odds ratio from logistic regression, with normal weight as the reference category with binary BMI as the outcome.
*p < .05.
**p < .01.

We found that about one-quarter of youth transition to a "healthier" weight: 28.1% of youth with overweight/obesity in Wave 1 transitioned to a normal weight in Wave 2 and 27.3% of youth with overweight/obesity in Wave 2 transitioned to a normal weight in Wave 3. Similar findings were reported from Spain, where 26% of youth classified as obese transitioned to overweight status.[4] Over one-quarter of youth transitioning to a lower BMI category indicates the need for future research into attitudes, behaviours and peer and school effects in these youth. This will provide valuable lessons as to how youth successfully achieve a healthier weight.

BMI also tends to increase in adults, and there are fewer reported decreases than in youth. Over a span of 18 years, BMI in adults in the USA increased by 13% (equivalent to 3.1), with only 1.9% of women and 0.5% of men having a 1 unit decrease in BMI.[5] Our and others' findings[4] that a proportion of youth with overweight/obesity tend to transition to lower BMI categories emphasizes the importance of healthy weight loss and maintenance during adolescence.

From the point of obesity and chronic disease prevention, school-based interventions are warranted as they also associated with decreases in substance use.[44,45] Participatory approach programs, which are gaining popularity because of their success, encourage youth to participate and have succeeded at retaining students[46] as well as leading to decreases in BMI.[47] A meta-analysis shows that problem-solving training and techniques from cognitive behavioural therapy were beneficial, as were programs based on a social influences approach that teaches refusal skills.[48]

Tailored prevention and intervention programs (such as gender-specific programs) are reportedly more effective than those intended for the general population of youth.[49] Our findings are important because they show that youth have gender-specific longitudinal predictors of BMI, warranting targeted gender-specific prevention and intervention efforts. We recommend gearing school-based interventions for inactivity and substance use that promote healthy food intake specifically towards male students and unhealthy dieting behaviours specifically towards female students. The scientific literature supports that addressing more than one health behaviour simultaneously is associated with more desired intervention-outcomes especially when a recommendation for increasing physical activity or limiting screen time predominates.[50,51]

Strengths and limitations

Our study contributes to the discussion that CDRB are associated with youth health differently over time and between the genders. Our study adopted a novel approach by taking into consideration the dependence of students in schools in both the gender-specific multilevel latent class analysis and the gender-specific multilevel longitudinal regression analyses. Our findings suggest that increases in BMI at follow-up were significantly associated with the latent class, inactive non-using youth in males; there were no such associations in females. Similar studies that only adjusted for gender might have not found any association because they did not stratify by gender.[6] In addition, we accounted for monotone type missingness by using maximum likelihood models, based on the assumption that data are missing at random. These models are preferable over those that are based on complete case analysis because the latter assume the outcome is missing entirely at random.[31]

In terms of limitations, the student questionnaire is entirely self-reported and therefore subject to social desirability bias. However, previous analyses have shown that there are no significant differences in the prevalence of BMI in COMPASS self-reports versus those measured by a trained professional across a national sample of youth in Canada.[17] COMPASS participants' self-reported BMI have a high validity compared with measurements made by a trained professional (ICC = 0.84).[23]

In addition, the use of passive consent likely mitigates social desirability bias. Active consent procedures are discouraged when measuring substance use to avoid limiting the participation of substance users who are most likely to benefit from these programs.[52]

Only two latent classes were used in the analysis: active experimenters and inactive non-using youth. This does not mean that other youth were left out of the analyses; rather, it indicates that some youth may have had a better fit with another latent class, for example, inactive substance user.[17] To conduct our longitudinal analysis, the classes had to be fixed in this manner across the 3 years so that comparisons could be made over time.

Lastly, COMPASS is not generalizable to youth across Canada since it uses purposeful sampling. However, the prevalence of substance use and of BMI was comparable to those found in a nationally representative sample.[53]

Conclusion

Although previous cross-sectional analyses show that youth in latent classes with substance use are associated with higher BMI and higher odds of overweight/obesity,[17] our longitudinal findings indicate that inactive male youth who do not use substances are at 72% higher odds of overweight/obesity than their active peers who experiment with substance use. This indicates that physical activity plays a longitudinal role in male youth BMI. No longitudinal predictors of increase in BMI were identified in female youth when considering latent classes of physical activity and current substance use.

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Conflicts of interest

The authors have no conflicts to report.

Authors' contributions and statement

NH conceived this study and its design, conducted the analysis and drafted the manuscript as part of her PhD dissertation at the University of Waterloo.

AC supervised NH in the drafting of the manuscript, co-designed the analyses, interpreted the results and edited the manuscript's content.

STL conceived the COMPASS study and wrote the funding proposal, developed its tools and is leading its implementation and coordination.

AC, STL and PB provided ideas and thoughts for discussion.

All authors supported NH in the development of the study design, revision of earlier manuscript drafts and approved the final manuscript.

The content and views expressed in this article are those of the authors and do not necessarily reflect those of the Government of Canada.

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Original quantitative research

Validation of Canproj for projecting Canadian cancer incidence data

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Abstract

Introduction: Cancer projections can provide key information to help prioritize cancer control strategies, allocate resources and evaluate current treatments and interventions. Canproj is a cancer-projection tool that builds on the Nordpred R-package by adding a selection of projection models. The objective of this project was to validate the Canproj R-package for the short-term projection of cancer rates.

Methods: We used national cancer incidence data from 1986 to 2014 from the National Cancer Incidence Reporting System and Canadian Cancer Registry. Cross-validation was used to estimate the accuracy of the projections generated by Canproj and relative bias (RB) was used as validation measure. The Canproj automatic model selection decision tree was also assessed.

Results: Five of the six models had mean RB between 5% and 10% and median RB around 5%. For some of the cancer sites that were more difficult to project, a shorter time period improved reliability. The Nordpred model was selected 79% of the time by Canproj automatic model selection although it had the smallest RB only 24% of the time.

Conclusions: The Canproj package was able to provide projections that closely matched the real data for most cancer sites.

Highlights

- The range of models Canproj offers allows for making reliable projections for most cancer sites.
- When there were variations in incidence rates, a recent, shorter time period could be used as the projection base to improve the accuracy of the projected incidence rates.
- For the national dataset, the Nordpred model was the one most often selected by the Canproj decision tree.
- Nordpred was the model with the smallest relative bias (RB) 24% of the time, nevertheless it was selected by Canproj decision tree 79% of the time.

Keywords: *neoplasms, forecasting, validation studies*

Introduction

For the past 30 years, the Canadian Cancer Society and the Government of Canada (Public Health Agency of Canada and Statistics Canada) have published an annual comprehensive report, *Canadian Cancer Statistics* (CCS). The report includes a series of population cancer incidence and mortality counts and rate projections that fill the gap between the latest available year of data and the year the report is released. These projections are a planning and prioritizing resource for stakeholders; they also keep the Canadian population informed on the considerable burden of cancer.

A few projection models have been used over the years to produce the CCS. The Poisson regression[1] used from 2003 to 2012 changed to Nordpred in 2011/2012. Nordpred, an R-package that was developed in Norway, makes available one single projection model, the age–period–cohort (APC) model with a drift component.[2] Nordpred is a well-studied package that has been shown to improve the reliability of cancer projections.[3-7]

In an effort to further cancer projections, Qiu et al. developed Canproj, which is also an R-package.[8] Canproj has three key advantages over Nordpred: 1) replacement of the Poisson distribution by the negative-binomial distribution when overdispersion is present; 2) inclusion of an age–cohort model; and 3) a set of hybrid models that combine the strengths of Poisson or negative-binomial regression, the segmented regression method,[9] and an average method for projections based on age-specific counts. Some of the features of Canproj were used for the 2017 CCS[10] while the full package was utilized for the 2019 CCS.

Canproj is a relatively new cancer-projection tool that has neither been extensively used nor validated.[11,12] The objective of our project was to validate the national short-term (up to 5 years) cancer incidence projections generated by the Canproj package using Canadian data. Specifically, we compared the outputs of the Canproj

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projection models to actual data using the holdout cross-validation method[13] and graphical representation. We also evaluated the automatic model selection features of Canproj (decision trees) to assess the capacity of these functions to select the best model.

Methods

Data

Cancer incidence data from 1986 to 2014 from the National Cancer Incidence Reporting System (NCIRS) and Canadian Cancer Registry (CCR) were used for the analysis.[14] Data from the province of Quebec were not included since the provincial cancer registry has not submitted new data to the CCR since 2010. The data file used the International Agency for Research on Cancer's international rules for multiple primary cancers.[15] Results were tabulated for all cancers combined, by cancer site (the same cancer sites as those included in the CCS annual reports) and sex.[10] A dataset was created for each combination of sex (n = 2) and cancer type (19 common to males and females plus five sex-specific types: cervix, ovary, uterus, prostate and testis). Datasets contained information by years from 1986 to 2014 and eighteen 5-year age groups (0–4, 5–9, …, 85+). Annual population estimates by geography, age and sex were provided by Statistics Canada with postcensal population estimates based on the 2016 Canadian census.[16] Inter- and postcensal estimates were adjusted by Statistics Canada for net under-coverage. Rates were age standardized using the direct method and the 2011 Canada population.[17]

Canproj

The Canproj R-package contains several models used to project cancer incidence or mortality data. These include the Nordpred model, which incorporates age, drift, period and cohort effects; the age–cohort model; three hybrid models that incorporate age and potentially period effects (age-specific or all ages); and the 5-year average model (Table 1).[18]

The Canproj package uses two decision trees to determine which model is the most appropriate based on the significance of the variables. Alternatively, models can be selected individually. At first, Canproj considers four variables, namely age, period, cohort and a drift parameter; this is the most complex model, and these

TABLE 1
Models available in the Canproj R-package and variables included in the models

Model[a]	Model variables			
	Age	Period	Cohort	Drift
Nordpred	✓	✓	✓	✓
Age–cohort	✓	–	✓	–
Hybrid age-specific trend[b]	✓	✓	–	–
Hybrid age-common trend[c]	✓	✓	–	–
Hybrid age only (average)[d]	✓	–	–	–
5-year average[e]	✓	–	–	–

[a] Poisson or negative-binomial distribution can be selected for Nordpred and the age–cohort and hybrid age-specific models.
[b] The period trend is calculated by age group.
[c] The period trend is common to all age groups.
[d] Rate average based on a number of years determined by the magnitude of the age-standardized rate.
[e] Rate average based on the most recent 5 years of data.

are the variables Nordpred uses. Canproj first determines if the cohort variable is significant. If it is significant, Canproj determines if the drift parameter is significant. If the cohort variable and the drift parameter are both significant, Canproj selects the Nordpred model to make the projections. If the cohort variable is significant but the drift parameter is not, Canproj selects the age–cohort model.

If the cohort effect is not significant, Canproj selects one of the hybrid models. If the number of cases is too small to run a regression model, a 5-year average is calculated. If the number of cases is big enough, Canproj will fit two models: an "age-common trend" model and an "age-specific trend" model. If the age-specific trend model has a better fit, then this model is selected. If not, the age-common trend model is selected. The slope of the common trend variable is then tested to determine if it differs from zero. If it is not different, then only the age variable is used in the model; if it is, the age + common trend model is used.

Validation

Cross-validation was used to estimate the accuracy of the Canproj-generated projections by using a subset of the data (the training data) and validating the results on the other subset (the independent testing data). This study used the holdout method[13] to create the training and the independent testing datasets. Data from 1986 to 2010 (five 5-year periods) were used as the training data, and data from 2011 to 2014 (the last 4 years of data) were used as the independent testing data. The predictions from the training model and the actual data from the last 4 years were compared to evaluate the accuracy of the projection models.

The validation measure we used, the relative bias (RB), compares the expected value generated by the projection models to the observed values in the testing dataset for diagnosis years 2011 to 2014. The RB measures the relative difference in percentage between the expected (or projected) value (E) and the observed value (O).

$$RB_t = \frac{|E_t - O_t|}{O_t} \times 100,$$

where t = 2011 to 2014

In our case, the "value" investigated is the age-standardized rate.

The RBs were summarized by projection model, cancer type and sex.

We compared the mean and median RBs by model, cancer type and sex over the 4-year projected (testing) period. Median RB indicates the typical performance of a model, whereas mean RB (due to its sensitivity to extreme values) helps reveal models that are typically accurate but occasionally very inaccurate.

Joinpoint analyses

We used Joinpoint Trend Analysis Software version 4.5.0.1 (National Cancer Institute, Bethesda, MD, USA)[19] to calculate trends in Canadian cancer incidence by type and sex between 1986 and 2010. Joinpoint model estimates were used to calculate the 1986 to 2010 RBs. This measure gives an estimate of the variability of the

TABLE 2
2011–2014 median relative bias (%) by model and cancer type

Sex	Cancer type	Model[a]						Diagnostic		
		Nordpred	Age–cohort	Hybrid		Age only	5-year average	JP[b]	RB ratio[c]	RB (%)
				Age-specific trend	Age-common trend					
Male	All cancers	11.0	10.1	5.9	**5.6**	7.8	7.5	**2007**	**5.7**	1.0
	Oral	8.8	13.4	14.8	12.7	**1.0**	6.3	**2003**	0.7	1.3
	Esophagus	2.6	**2.2**	3.0	2.7	5.9	2.2	**2005**	0.8	2.8
	Stomach	**3.1**	3.8	3.9	3.9	25.2	8.5	1986	1.6	1.9
	Colorectal	7.4	7.7	**6.4**	8.1	10.2	7.8	**2008**	**16.0**	0.4
	Liver	4.4	4.2	4.8	**3.9**	26.2	10.0	1986	1.0	4.0
	Pancreas	**3.0**	6.9	6.5	5.4	3.1	3.5	1997	**2.3**	1.3
	Larynx	**1.4**	3.6	2.4	2.0	44.0	18.2	1986	0.6	2.4
	Lung and bronchus	3.1	1.8	1.9	**1.7**	30.2	11.1	1986	1.3	1.3
	Melanoma	**1.4**	6.1	1.5	4.6	17.6	8.3	1986	0.7	2.0
	Breast	4.9	**4.3**	6.3	6.0	6.6	6.7	1986	0.6	6.9
	Prostate	48.4	90.1	41.4	44.4	33.8	**33.1**	**2001**	**11.2**	2.9
	Testis	1.4	1.4	1.3	**1.3**	13.9	7.2	1986	0.3	4.4
	Urinary bladder	10.1	15.9	12.4	14.7	9.8	**9.3**	1990	**3.5**	2.7
	Kidney and renal pelvis	5.0	2.8	2.0	**2.0**	9.1	4.8	1998	1.0	1.9
	Brain/CNS	4.1	**2.9**	4.3	3.4	7.7	5.6	1986	1.5	2.0
	Thyroid	**3.7**	17.0	13.0	13.0	48.9	27.4	1997	0.8	4.6
	Hodgkin lymphoma	1.4	1.4	2.1	1.6	3.4	**1.3**	1986	0.5	2.6
	Non-Hodgkin lymphoma	7.7	7.4	**6.6**	7.3	8.5	7.8	**2007**	**4.4**	1.5
	Myeloma	5.2	4.7	5.1	**4.6**	10.0	6.8	1986	1.3	3.6
	Leukemia	6.2	3.8	6.1	5.2	**0.8**	3.5	1994	0.4	2.0
	All others	4.0	4.1	2.8	**2.8**	4.5	3.6	**2003**	**2.1**	1.3
Female	All cancers	0.9	**0.8**	0.8	0.8	3.3	0.9	1986	1.0	0.8
	Oral	3.1	4.2	4.2	4.2	**1.7**	2.8	1986	0.6	2.9
	Esophagus	1.1	1.1	1.5	**0.9**	6.8	1.3	1986	0.3	3.4
	Stomach	**1.3**	2.7	7.2	4.4	20.5	3.5	1992	0.6	2.0
	Colorectal	4.0	3.7	**2.7**	4.2	8.3	4.9	2000	**5.5**	0.5
	Liver	5.3	4.8	5.1	**4.4**	21.2	8.9	1986	0.7	6.4
	Pancreas	4.3	5.1	5.5	4.9	**3.5**	4.2	1986	1.4	2.5
	Larynx	**10.0**	13.6	17.3	15.1	64.1	28.5	1986	1.8	5.5
	Lung and bronchus	1.3	**1.3**	9.0	4.9	3.9	1.9	**2006**	**2.1**	0.6
	Melanoma	**2.8**	8.4	3.5	3.4	16.3	9.3	1992	1.4	2.0
	Breast	2.3	3.2	**0.7**	1.3	1.9	1.6	1991	0.4	1.9
	Cervix uteri	3.4	4.7	**1.4**	1.4	22.3	8.6	**2006**	0.7	2.1
	Uterus	3.1	8.0	3.4	**2.6**	10.0	10.0	**2005**	1.8	1.5
	Ovary	1.1	**1.1**	1.2	1.7	9.9	4.7	1986	0.6	1.7
	Urinary bladder	14.1	14.2	13.1	14.5	10.1	**9.7**	1986	**3.1**	3.1
	Kidney and renal pelvis	12.0	4.3	4.6	4.3	6.1	**4.2**	1986	1.8	2.4
	Brain/CNS	5.6	**5.3**	5.7	5.5	8.8	6.2	1986	**2.2**	2.4
	Thyroid	**4.5**	6.3	5.4	5.9	50.1	21.7	**2005**	**2.7**	1.7
	Hodgkin lymphoma	10.3	10.9	12.2	11.6	**8.0**	10.4	1986	**2.4**	3.4
	Non-Hodgkin lymphoma	5.3	4.9	**4.4**	4.9	5.8	6.0	1997	**3.9**	1.1
	Myeloma	**3.8**	4.1	3.9	3.9	6.8	4.2	1986	1.0	3.7
	Leukemia	14.3	5.0	4.7	6.8	**2.6**	4.8	**2001**	1.5	1.7
	All others	3.1	4.2	3.6	4.1	**3.0**	3.1	**2004**	**3.5**	0.8

Abbreviations: CNS, central nervous system; JP, joinpoints; RB, relative bias.

[a] Models with the smallest 2011–2014 median RB are highlighted in light green.

[b] Year of most recent joinpoint for rate trends. Joinpoints that happened between 2001 and 2005 are highlighted in yellow, while joinpoints that happened between 2006 and 2008 are highlighted in orange.

[c] The RB ratio is the ratio of median RB for the 2011–2014 period to the median RB for the 1986–2010 period. In order to show the cancer sites that were more difficult to model, the continuous RB ratios were grouped as follows: The yellow highlighting means the 2011–2014 median RB is 2 to 5 times higher than the 1986–2010 median RB; the orange highlighting means the 2010–2014 median RB is more than 5 times higher than the 1986–2010 median RB.

training data, which we compared to the RB measured on the projected data. The maximum number of joinpoints was set to 4; the minimum number of observations from a joinpoint to either end of the data was set to 3; and the minimum number of observations between two joinpoints was set to 4. Otherwise, the default joinpoint parameters were used. The log-transformed age-standardized rates and associated standard errors input into joinpoint were calculated in statistical package SAS version 9.3 (SAS Institute Inc., Cary, NC, USA). Canproj was run using R version 3.5.1 (R Foundation for Statistical Computing, Vienna, Austria) and RStudio version 1.1.453 (RStudio Inc., Boston, MA, USA).

Performance indicators

Two indicators were used to highlight which models would likely project rates less reliably. The first was the identification of a joinpoint over the most recent 10-year period in the data used to train the projection models (2001–2010). Recent changes in the trend could indicate that the models will have more difficulty performing reliable projections. We divided the joinpoints between those that happened between 10 to 6 years before the last year of training data available and those that happened 5 to 3 years before the last year of data. Joinpoints were not allowed to occur between 0 and 3 years. In Table 2, yellow cells indicate joinpoints that happened between 2001 and 2005 and orange cells indicate those that happened between 2006 and 2008.

For the second indicator, we used the RB ratio, which is the ratio of RB from 1986 to 2010 to the RB for the 2011–2014 period. We considered that the bias from the projected rates should be at least equal to or greater than the bias in the rates that were used to build the projection models. To obtain the 1986 to 2010 RB, we used the output of the joinpoint analysis. In Table 2, if the 2011–2014 RB was 2 to 5 times higher than the 1986–2010 RB, table cells are in yellow; if the 2011–2014 RB was more than 5 times higher than the 1986–2010 RB, the cells are in orange. These cutoffs were arbitrarily determined after looking at the distribution of the results.

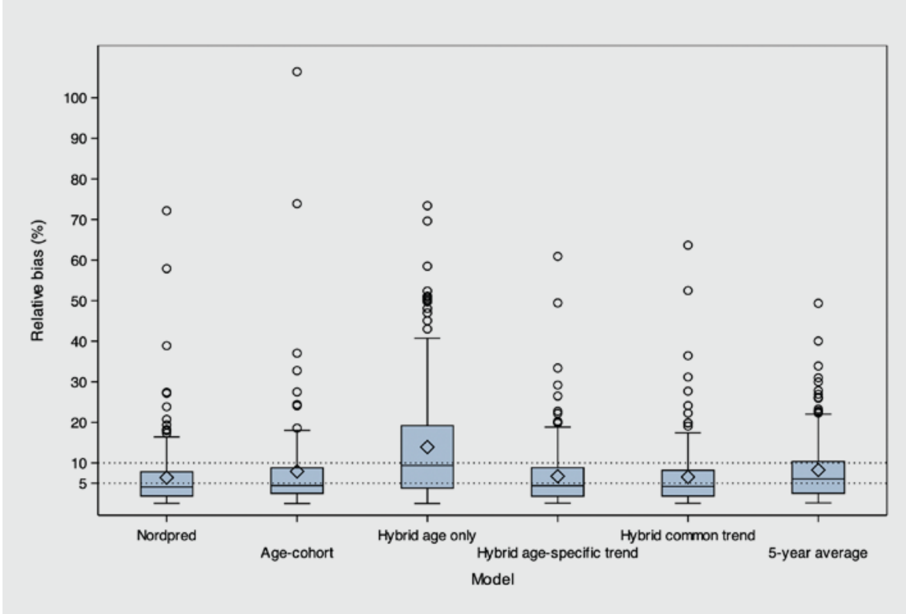
Results

Canproj models

Five of the six models (Nordpred, the age-cohort model, the hybrid common trend model, the hybrid age-specific trend model and the 5-year average model) had mean RB between 5% and 10% and a median RB around 5% (Figure 1). Greater variation was observed in the mean and median RB when the accuracy of the projection models was compared by cancer site (Figure 2). None of the models were good at predicting prostate cancer and a greater predictive variability was apparent for cancers of the thyroid, larynx, bladder, liver and brain/central nervous system (CNS).

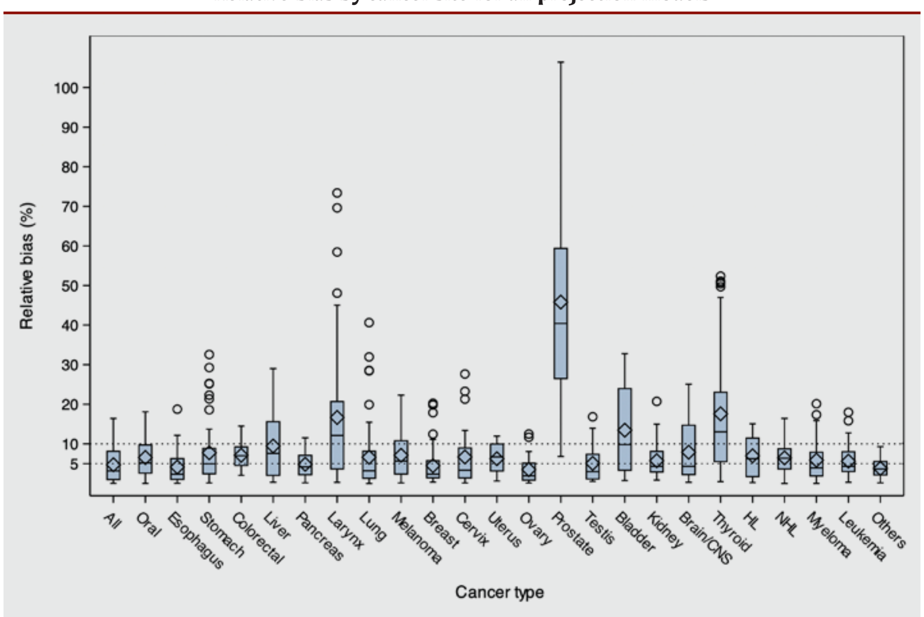
A more detailed and slightly different picture emerges when models are graphically compared by type of cancer and sex (Figure 3, Table 2). The performance of all projection models was poor for male all cancer sites combined, male and female

FIGURE 1
Relative bias by projection model for all cancer sites



Note: See the following link for details about box plots: http://onlinestatbook.com/2/graphing_distributions/boxplots.html

FIGURE 2
Relative bias by cancer site for all projection models



Abbreviations: CNS, central nervous system; HL, Hodgkin lymphoma; NHL, non-Hodgkin lymphoma.
Note: See the following link for details about box plots: http://onlinestatbook.com/2/graphing_distributions/boxplots.html

FIGURE 3
Actual age-standardized incidence rates (1986–2010) and projected age-standardized rates (2011–2014) obtained with Canproj projection models by sex and cancer site, Canada

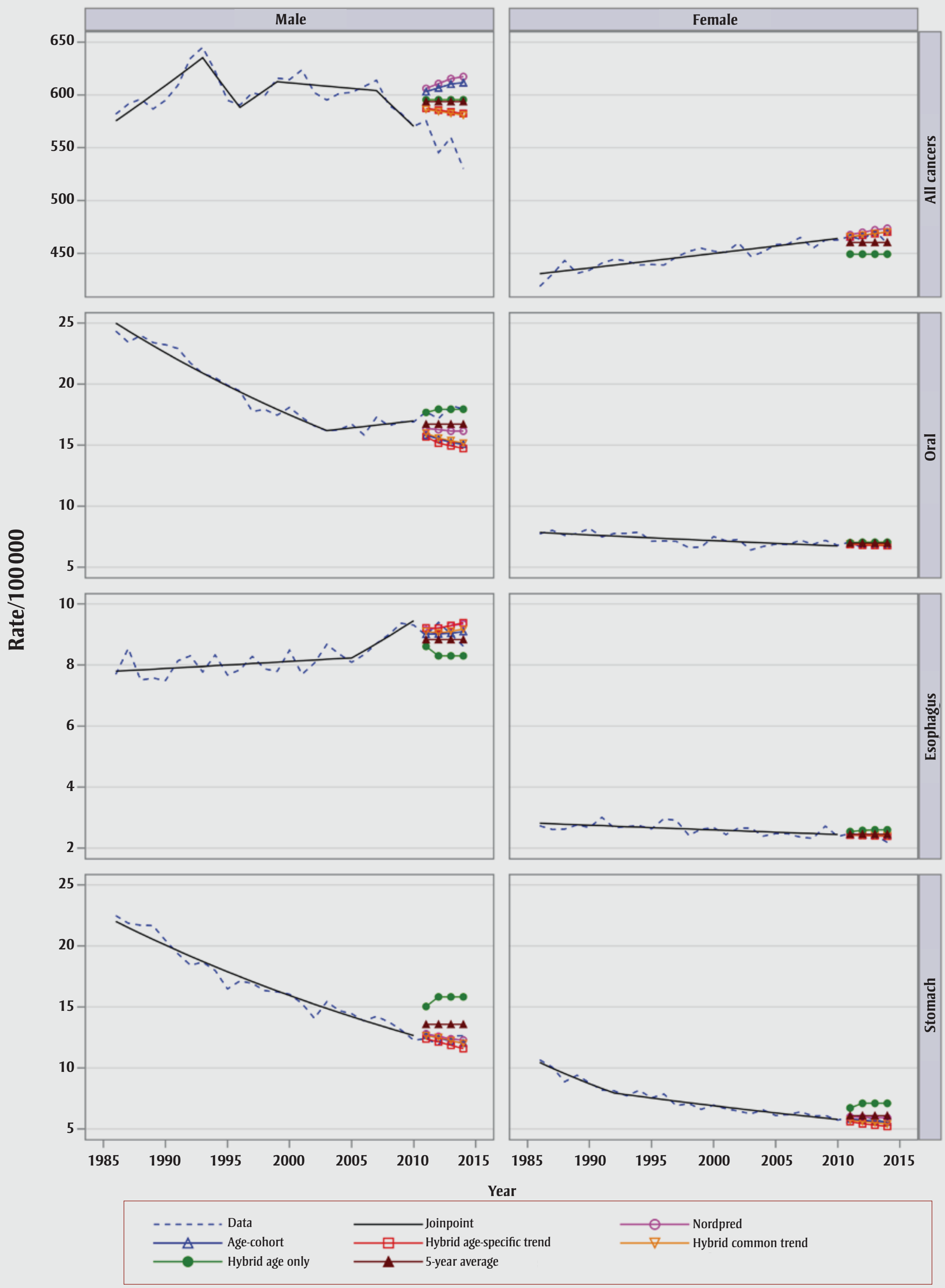


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FIGURE 3 (continued)
Actual age-standardized incidence rates (1986–2010) and projected age-standardized rates (2011–2014) obtained with Canproj projection models by sex and cancer site, Canada

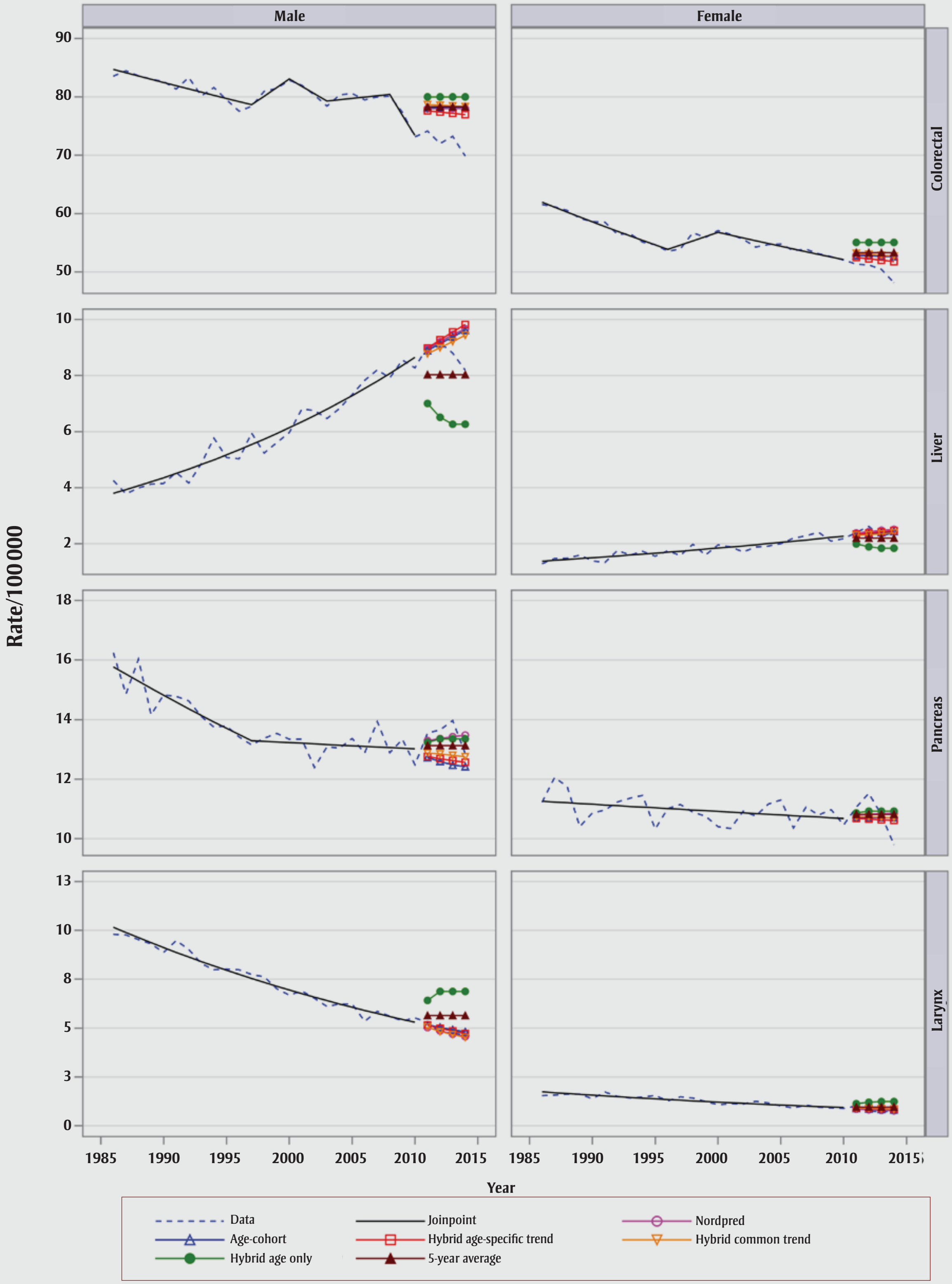

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FIGURE 3 (continued)
Actual age-standardized incidence rates (1986–2010) and projected age-standardized rates (2011–2014) obtained with Canproj projection models by sex and cancer site, Canada

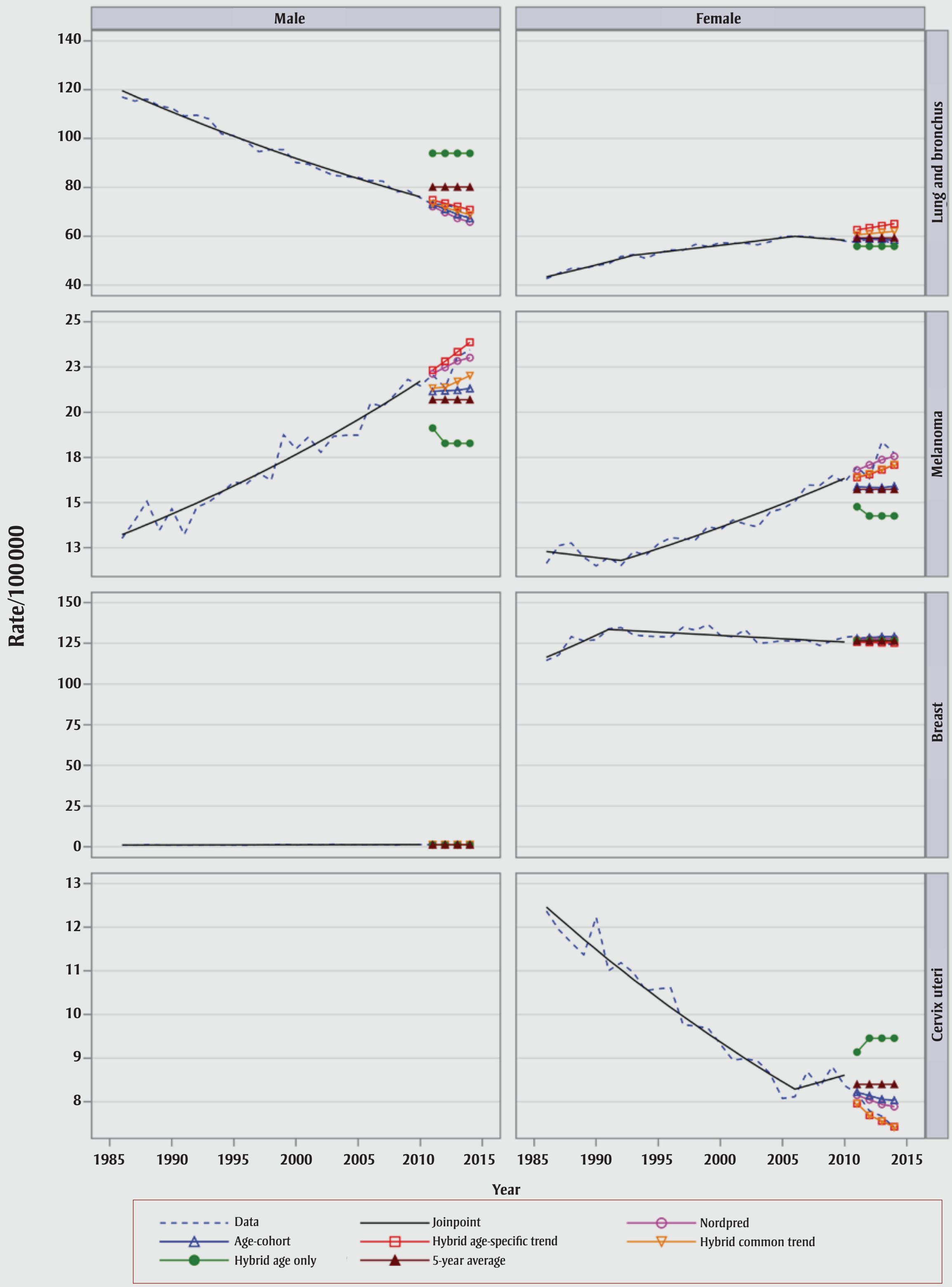

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FIGURE 3 (continued)
Actual age-standardized incidence rates (1986–2010) and projected age-standardized rates (2011–2014) obtained with Canproj projection models by sex and cancer site, Canada

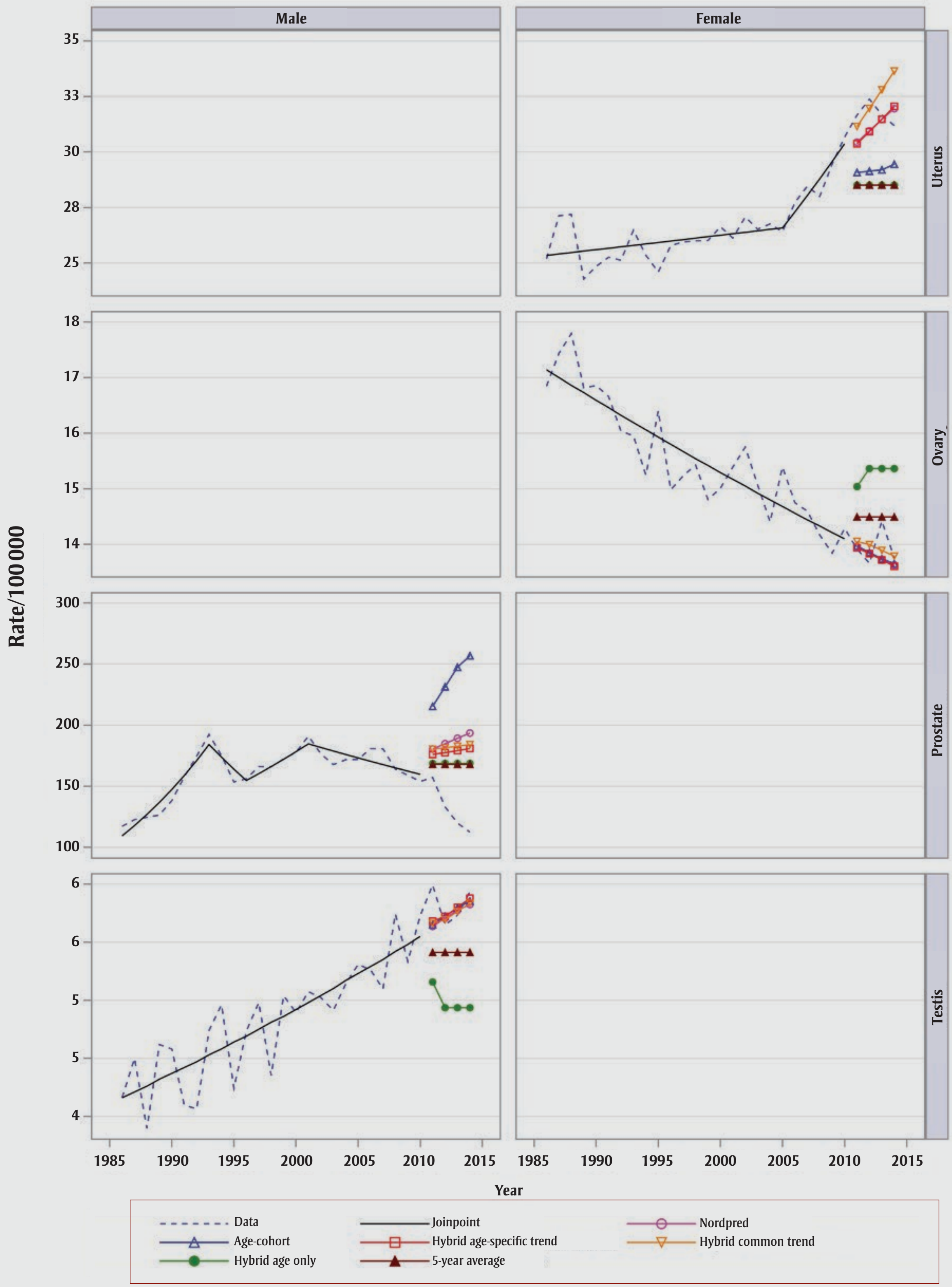

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FIGURE 3 (continued)
Actual age-standardized incidence rates (1986–2010) and projected age-standardized rates (2011–2014) obtained with Canproj projection models by sex and cancer site, Canada

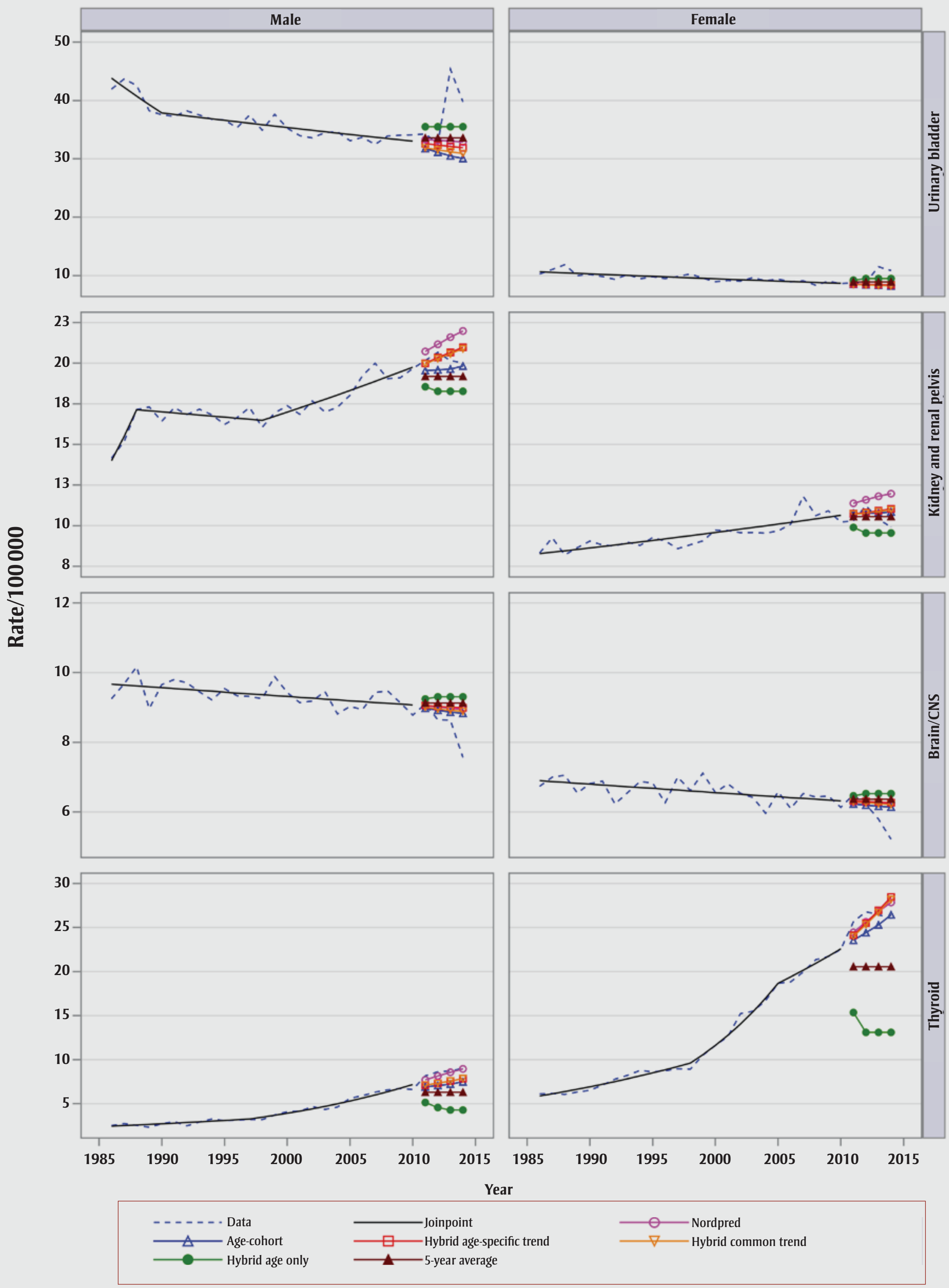

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FIGURE 3 (continued)
Actual age-standardized incidence rates (1986–2010) and projected age-standardized rates (2011–2014) obtained with Canproj projection models by sex and cancer site, Canada

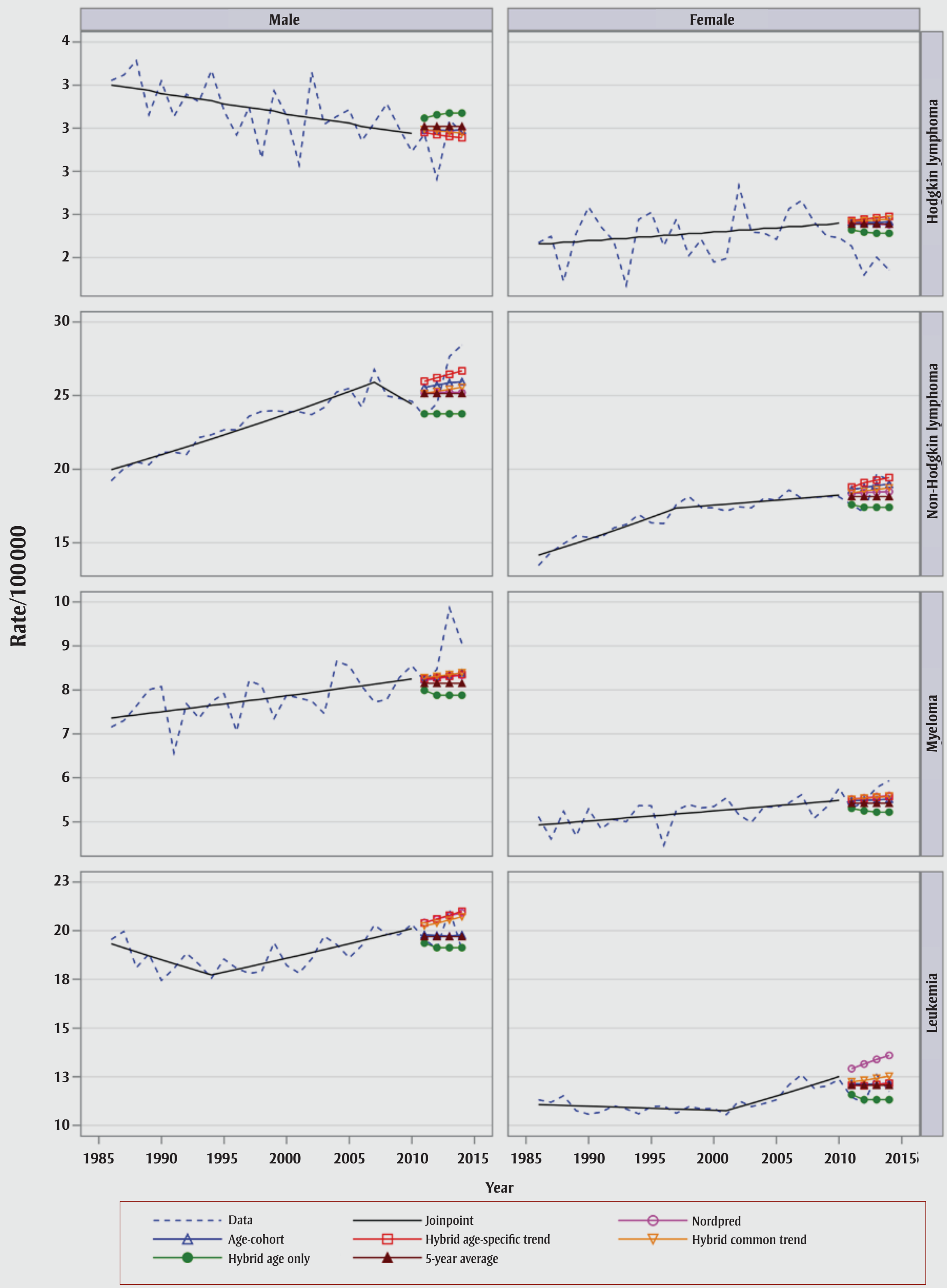

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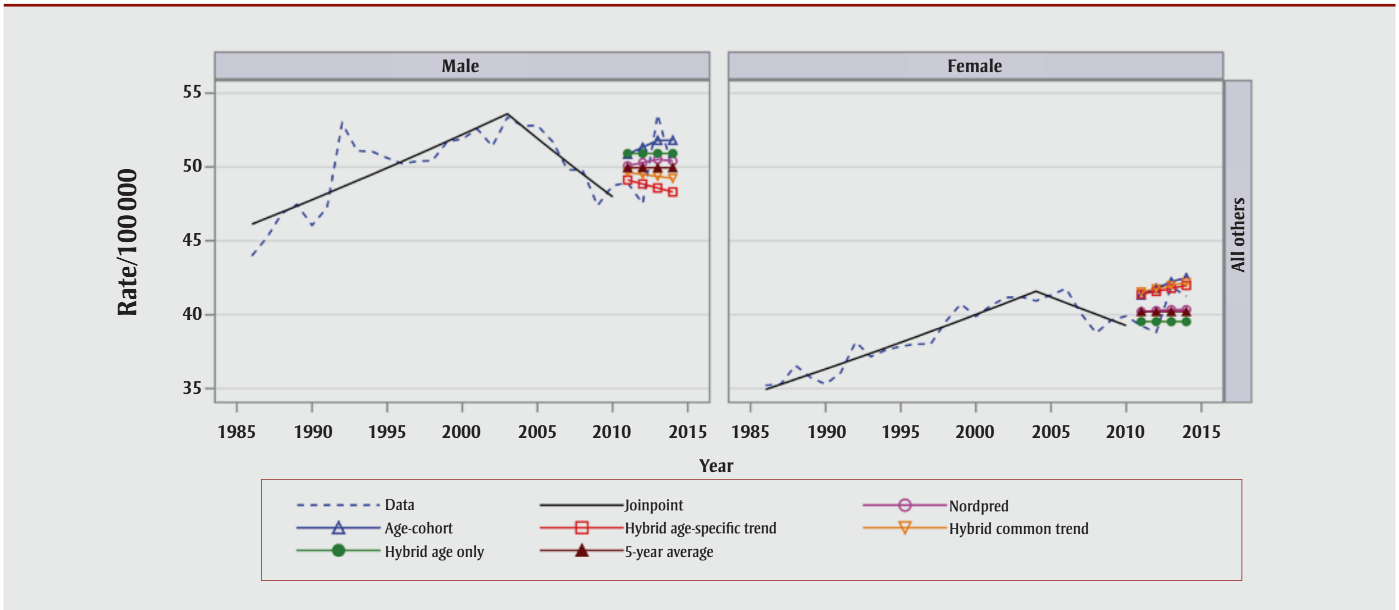
FIGURE 3 (continued)
Actual age-standardized incidence rates (1986–2010) and projected age-standardized rates (2011–2014) obtained with Canproj projection models by sex and cancer site, Canada



colorectal, prostate, male bladder, male and female brain/CNS, female Hodgkin lymphoma and male myeloma. The greater variation observed in Figure 2 for cancers of the liver, larynx and thyroid seems to be due to the inability of a few models to predict rates.

Cancer sites that showed recent change in trend for which projections could potentially be improved by changing the length of the data included male all cancers, male and female colorectal cancer and prostate cancer. We ran separate hybrid models on these cancers sites using the last 7 years of data only. It was possible to increase the fit of the projections substantially for all four cancer sites. For colorectal cancer, it was possible to bring the RB ratio from 16.0 to 2.6 for males and from 5.5 to 1.9 for females. We were also able to bring the RB ratio from 5.7 to 5.4 for male all cancers combined and from 11.2 to 7.7 for prostate cancer.

Canproj model decision trees

As shown in Table 3, the cohort effect and the drift parameter were significant 79% of the time (34 out of 43 models), which makes Nordpred the model most often selected by Canproj. However, Nordpred was the model with the smallest RB only 24% of the time. Nevertheless, the mean RB was between 0 and 5% for at least one of the six models 76% of the time and between 6% and 10% for at least one model 20% of the time.

Discussion

Our aim was to validate short-term projections generated by Canproj using Canadian cancer incidence data. The results show that the range of models Canproj offers supports making reliable projections for most of the cancer sites investigated. When variations in rates were identified within the last 10 years of training data, it was possible to use the recent, shorter time period as the projection base for the hybrid models to improve the accuracy of the projected rates.

The large jump in bladder cancer rates in 2013/2014 is due to changes in reporting rules in Ontario;[20] starting in 2013, Ontario added in situ bladder to malignant bladder cancer in their registry.

Brain/CNS, colorectal cancer, female Hodgkin lymphoma, prostate and male all cancer combined rates are declining faster than the models predicted, while male myeloma is increasing faster than the models predict. The poor performance at predicting these cancer rates is related to the recent and rapid changes in their rates that were not part of the training dataset or happened in the last few years of the training dataset.

We evaluated the automatic model selection feature of Canproj (decision trees) to assess the capacity of these functions to select the best model. For the national dataset, Nordpred was the model most often selected by Canproj decision tree although it was the one with the smallest RB only 24% of the time. Other models can outperform Nordpred when analyzing data from smaller populations.[21] Personal and others' experiences with Canproj suggest that the decision tree selection should be used in combination with individual outputs of each model and expert advice to select the best projection model.[22]

The results of this project build on prior Canadian studies that examined different cancer projection methods. Lee et al. (2011) compared the accuracy of 16 models and model variations for projecting short-term cancer mortality rates.[23] They found that no single method was able to consistently provide accurate forecasts for a wide range of cancer sites and that a choice of models is preferable. Qiu et al. (2010) compared the Nordpred model, the generalized additive model and the Bayesian model.[8] They concluded that when the age, drift and cohort effects are present, the Nordpred method is the preferred approach; when the age and cohort effects are present, an age–cohort model is the best approach; and when the cohort effect is not present, a hybrid method should be used. They also found that for

TABLE 3
Canproj decision tree: average relative bias by model, sex and cancer site

Sex	Cancer type	Model					
		Nordpred	Age–cohort	Hybrid		Age only	5-Year average
				Age-specific trend	Age-common trend		
Male	All cancers	**10.9**	10.1	5.9	**5.7**	7.8	7.5
	Oral	**8.6**	13.2	14.8	12.6	**1.6**	5.9
	Esophagus	3.9	**2.6**	**4.2**	3.2	6.8	3.0
	Stomach	**3.4**	3.7	4.1	3.7	26.1	9.5
	Colorectal	**7.9**	8.2	**6.9**	8.6	10.7	8.3
	Liver	**6.8**	6.5	7.6	**6.2**	26.0	8.6
	Pancreas	3.2	7.0	**6.2**	5.0	**3.2**	3.8
	Larynx	**2.1**	3.6	2.5	2.2	39.4	16.2
	Lung and bronchus	**3.2**	1.7	2.6	**1.6**	32.4	12.9
	Melanoma	**2.1**	5.5	2.8	3.9	17.6	7.8
	Breast	**6.2**	6.8	8.6	**8.3**	6.4	6.2
	Prostate	**45.9**	86.4	38.9	41.8	31.3	**30.6**
	Testis	2.4	**2.4**	2.2	**2.1**	14.3	7.1
	Urinary bladder	**12.3**	17.3	13.7	15.9	**11.2**	11.6
	Kidney and renal pelvis	**5.5**	3.0	2.4	**2.3**	9.4	5.3
	Brain/CNS	**6.7**	**6.0**	7.0	6.3	10.0	8.0
	Thyroid	**3.3**	16.8	13.4	13.5	46.8	26.9
	Hodgkin lymphoma	**3.4**	3.4	3.5	3.4	**5.5**	3.8
	Non-Hodgkin lymphoma	**7.5**	7.2	**6.9**	7.0	8.5	7.5
	Myeloma	6.6	**6.3**	**6.6**	6.4	10.7	7.9
	Leukemia	6.0	3.9	**6.0**	5.5	**2.8**	3.6
	All others	**3.8**	4.8	3.8	3.6	4.6	**3.6**
Female	All cancers	**1.3**	1.1	**1.0**	1.1	3.4	1.1
	Oral	3.4	**4.1**	4.4	3.9	**2.9**	3.3
	Esophagus	3.6	3.5	3.2	**3.0**	8.8	3.9
	Stomach	**2.7**	2.9	7.2	4.1	20.7	4.9
	Colorectal	**5.2**	4.9	**3.7**	5.4	9.5	6.1
	Liver	**5.4**	**4.9**	5.2	5.5	21.8	9.0
	Pancreas	4.9	5.1	5.2	5.0	**4.9**	**4.7**
	Larynx	**10.2**	14.5	16.7	15.3	53.4	24.0
	Lung and bronchus	**1.6**	1.6	10.3	5.8	3.5	2.4
	Melanoma	**3.0**	8.4	4.2	4.1	16.9	9.1
	Breast	**2.3**	2.9	**1.2**	1.5	1.8	1.7
	Cervix uteri	**3.4**	4.6	1.5	**1.5**	20.9	8.3
	Uterus	**2.8**	7.9	3.0	3.6	10.1	10.1
	Ovary	**1.9**	**1.8**	1.8	1.8	9.7	4.0
	Urinary bladder	**14.6**	14.7	13.7	15.0	**10.7**	10.7
	Kidney and renal pelvis	**12.0**	5.4	6.0	5.8	7.7	**4.1**
	Brain/CNS	**7.8**	**7.1**	8.2	7.7	10.8	9.1
	Thyroid	**4.3**	5.7	5.5	5.3	47.9	21.6
	Hodgkin lymphoma	10.1	**10.5**	11.5	11.0	**7.9**	10.0
	Non-Hodgkin lymphoma	**5.6**	5.3	5.4	**5.3**	5.8	5.7
	Myeloma	**3.7**	3.9	**3.8**	3.8	6.4	4.4
	Leukemia	**13.2**	5.6	5.2	6.4	**4.1**	5.1
	All others	**3.0**	4.2	3.7	4.0	3.1	3.2

Abbreviations: CNS, central nervous system; RB, relative bias.
Notes: Light green cells are the projection models Canproj selected; lilac cells are the models with smallest RB; dark green cells indicate that the Canproj selection is the model with the smallest RB.

small cancer sites, data aggregation is required to apply the hybrid method. In 2010, the Canadian Cancer Projections Network (C-Proj) released a report in which they evaluated Nordpred, hybrid, age–cohort and Bayesian models using Markov chain Monte Carlo cancer incidence projection methods with data from the Nova Scotia Cancer Registry.[21] They suggested that the age–cohort method should be used for cancer projections for provinces with small and stable populations.

Although cancer incidence projections are routinely performed, only a few studies describe the evaluation of alternative methods; the recommendations depend on the population included and projection time frame. Stock et al. (2018) used a Bayesian approach to project cancer incidence rates to 2030 using data from the German cancer registry.[24] They found that this method offered advantages in terms of flexibility, interpretability, transparency and level of detail, but they did not recommend using it for short-term data. Pesola et al. (2017) compared a number of models (null, age–drift, age–period, age–cohort and APC) to predict pediatric and adolescent cancer incidence in England to 2030.[25] The model fit results showed that the age–drift model offered as good a fit to the data as more complex models for all cancers in children. An APC model with natural cubic splines was evaluated when predicting cancer incidence and mortality in the United Kingdom until 2035.[26] The basis of the APC model is that past trends will continue into the future. If vaccines or new treatments that change cancer incidence and mortality are developed, the model will not anticipate these changes, reinforcing the importance of using recent data and completing projections at regular intervals.[27] Katanoda et al. (2014) examined three projection models' ability to project short-term cancer incidence in Japan: generalized linear model with age and period as independent variables (A + P linear); generalized linear model with age, period and their interactions (A*P linear); and generalized additive model with age, period and their interactions smoothed by spline (A*P spline).[28] They used Nordpred in their preliminary analysis and it failed to predict the peak in liver cancer in the mid-1990s.

Strengths and limitations

This project has several limitations. In all the models Canproj uses, the variables age, period and cohort encompass all the changes and improvements in risk factors, demography and ethnic profile of the population, prevention, early detection and treatment. More details on these cancer rate determinants would improve the capacity for making more reliable projections. However, the level of information needed may be hard to obtain in some jurisdictions and, for most of the cancer sites investigated in the project, the age, period and cohort information has proven sufficient for making reliable projections.

We did not conduct a detailed Canadian provincial data analysis in the present exercise, but we expect that as provincial populations get smaller, models other than Nordpred would become the most frequently selected through the decision tree.

The data used in the models did not include data from the province of Quebec and consequently does not represent the entire country.

Finally, as with all methods, projections rely on the assumption that past trends will continue into the future, which may not always be the case.

Conclusions

Health care planners and policy makers need to know about the future burden of cancer to help them prioritize cancer control strategies, allocate resources and evaluate treatments and interventions. The Canproj package can provide reliable cancer projections to help them support their task.

Conflicts of interest

The authors have no conflicts of interest to declare.

Authors' contributions and statement

AD, ZQ and AS were involved in the design and conceptualization of the work.

AD and ZQ were in involved in the analysis of the data.

AD drafted the paper.

All authors provided input for the interpretation of the results and revision of the paper.

The content and views expressed in this article are those of the authors and do not necessarily reflect those of the Government of Canada.

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At-a-glance

Injury hospitalizations in Canada 2018/19

Xiaoquan Yao, MSc; Robin Skinner, MSP; Steven McFaull, MSc; Wendy Thompson, MSc

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Abstract

National injury hospitalization statistics are essential for understanding the burden and pattern of injuries. This paper used the Discharge Abstract Database to analyse injury hospitalizations in Canada (excluding Quebec) for fiscal year 2018/19. The results show that unintentional injuries were the eighth leading cause of hospitalization compared to all other diseases and conditions. For unintentional injury-related hospitalizations, in rank order, the leading causes were falls, suffocation, motor vehicle traffic crashes, poisonings, struck by/against, and fire/hot object/smoke. However, the rankings were different across age groups.

Keywords: *injury hospitalizations, leading causes, unintentional injuries, self-inflicted injuries, assault, falls*

Highlights

- National injury hospitalization statistics are essential for understanding the burden and pattern of injuries, including non-fatal events, in Canada and informing prevention strategies.
- In fiscal year 2018/19, unintentional injuries were the eighth leading cause of hospitalizations overall compared to all other diseases and conditions. They were ranked ninth or higher among causes of hospitalization for every age group except children aged less than 1 year old.
- Falls were the leading cause of hospitalization in every age group for unintentional injury-related hospitalizations.

Introduction

An injury is defined as the transfer of energy to human beings at rates and in amounts above or below the tolerance of human tissue.[1,2] Injuries can be grouped according to external cause, which is a rough representation of the main energy types: falls (mechanical); motor vehicle traffic crashes (MVT) (mechanical); struck by/against (mechanical); poisonings (chemical); suffocation (asphyxiation, too little energy); fire/hot object/smoke (thermal/chemical); and others (various energy types).

Injuries can also be classified as either unintentional or intentional. Unintentional injuries are those not caused on purpose or with intention to harm such as when someone trips and falls or is involved in a traffic accident.[3,4] Intentional injuries result from a deliberate act of harm to oneself (self-inflicted) or another person (assault).[3] When the intent is unclear, the injury is classified as undetermined intent. The intent and external cause provide insights into the mechanism of injuries that are fundamental for injury prevention.

Injuries are a public health concern, claiming 4.9 million lives worldwide in 2016[5] and resulting in many more hospitalizations, emergency department visits and doctors' appointments.[6] In Canada in 2018, 17 843 people died from injuries,[7] and in fiscal year 2017/18, there were more than 269 000 injury-related hospitalizations.[8] The economic burden associated with injuries in 2010 was around CAD 27 billion.[9]

Establishing a broad understanding of current injury burden and pattern in Canada is foundational for injury prevention efforts. Parachute, a national injury prevention organization, uses such information to set its strategic priority areas[10] and to form the basis for reports on economic burden and cost of injury.[9] Our 2019 paper showed that unintentional injuries were the first or second leading cause of death among 1–44 year olds and suicide was the second leading cause for those aged 15–34 years.[11]

Hospitalization statistics are essential to understanding injury burden including non-fatal events. Injury and trauma emergency department and hospitalization statistics for fiscal year 2017/18, published by the Canadian Institute for Health Information (CIHI), provide Canadian injury hospitalization rates by province/territory and hospitalization counts for specific injuries based on cause and intent.[8] In a 2013 study, the Public Health Agency of Canada (PHAC) presented national injury hospitalization statistics from another perspective: PHAC ranked the hospitalizations for certain injury groupings (unintentional, self-inflicted and assault) compared to other diseases or conditions.[12] That study also compared the hospitalizations associated with major external causes of injuries.[13] Presenting the data in this way allows a clear understanding of the relative burden of the major injury groupings, which can complement the CIHI statistics.

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The objective of this paper is to update the previous tables using the most current data available for Canada (2018/19, Quebec excluded). The information presented in this paper is intended to illustrate the burden and pattern of injury-related hospitalizations to inform injury-prevention initiatives.

Methods

Our data source was the Discharge Abstract Database (DAD) 2018/19 from CIHI, which does not include Quebec hospitals. For this study, we selected only discharges from acute inpatient institutions, which we refer to as hospitalizations. A total of 2 587 663 acute inpatient records with a discharge date between 1 April 2018 and 31 March 2019 were kept after excluding stillbirths, cadavers and duplicates. The number of records represented the discharge count, not the number of individual patients.

The diagnoses in DAD 2018/19 were coded in ICD-10-CA (the International Statistical Classification of Diseases and Related Health Problems, 10th Revision, Canada).[14] To compare the burden of unintentional injuries, self-inflicted injuries and assault to other diseases or conditions, we used the most responsible diagnosis (MRD) variable to determine the cause of a hospitalization. If a record's MRD starts with an S or T, the record is defined as an injury record and further classified into unintentional injuries, self-inflicted injuries, assault, injuries with undetermined intent or others based on the external cause code in the diagnoses. If multiple external causes were found for one record, the classification was assigned following a priority order as assault, self-inflicted injuries, unintentional injuries, injuries with undetermined intent and others.

We conducted additional analyses for injury-related hospitalizations. To capture all hospitalization cases associated with injuries, we searched all external cause codes regardless of S or T code in MRD. We classified injuries based on intent and then external cause for unintentional injuries (falls, suffocation, MVT, poisonings, struck by/against, fire/hot object/smoke). We did not include complications of medical and surgical care; these were not the focus of this paper because their nature and prevention measures differ from that of most injuries.[3] If a record was associated with multiple injury groups, it was counted multiple times.

We used SAS Enterprise Guide version 7.1[15] to compile the pooled and stratified (by sex and age) counts. The population estimates (Quebec excluded) on 1 October 2018 from Statistics Canada[16] were used for crude rate calculation.

Results

Leading causes of all hospitalizations

The leading causes of all hospitalizations are presented in Table 1. Compared to all other diseases and conditions (including hospitalizations due to examinations, specific care, potential hazards and reproduction-related circumstances and not classifiable symptoms, signs and findings), unintentional injuries ranked eighth overall, seventh among males and ninth among females. For every age group except less than 1 year olds, unintentional injuries were ranked ninth or higher. They were among the top five for 1–34 year olds and those aged 80 years and over. Self-inflicted injuries were the ninth leading cause of hospitalizations for 15–19 year olds and tenth for 20–24 year olds.

Leading causes of injury-related hospitalizations

Table 2 shows that overall, males and females had similar rank order in hospitalization rates for unintentional injuries, but diverged for intentional injuries. Females displayed higher rates of hospitalizations associated with unintentional falls and self-inflicted injuries than males. In contrast, males showed higher rates of hospitalizations associated with unintentional suffocation, MVT, poisonings, struck by/against, fire/hot object/smoke and assault.

For all ages combined, the rankings of unintentional injuries by external causes (from highest to lowest) were falls, suffocation, MVT, poisonings, struck by/against and fire/hot object/smoke. Across the lifespan, the rate of hospitalization associated with falls increased sharply among those aged 65 years and over, jumping to 4 times and then 16 times as much as 45–64 year olds.

Aside from falls as the leading cause of hospitalizations associated with unintentional injuries in every age group, we can see variations in the ranking of other external causes across age groups. Suffocation was the second leading cause for less than 10 year olds and those aged 45 years and over. MVT was the second leading cause for 15–44 year olds. Struck by/against was second for those aged 10–14 years.

Of note is that 15–24 year olds displayed a higher rate of hospitalization associated with self-inflicted injuries than unintentional falls. Those aged 20–24 years showed the highest rate of hospitalizations associated with assault.

Discussion

This paper presents the most up-to-date national injury hospitalization statistics to help understand the burden and pattern of injuries in Canada.

The results reveal that, overall, unintentional injuries were the eighth leading cause of hospitalizations in fiscal year 2018/19. Falls were the leading cause of hospitalizations related to unintentional injury across all age groups, particularly among seniors (65 years and over), with the rate jumping to 4 times and then 16 times as much as in middle age. The burden of seniors' falls on the Canadian health care system is substantial.[9] Moreover, the aging of the baby-boom cohort increases the proportion of the population aged 65 and over. Ongoing surveillance of falls in this population is very important to understand the trend and develop effective prevention programs.[17] The variations in the ranking of other unintentional injury groups across age groups highlight the significance of tailoring prevention efforts to specific age groups. They are the base for strategic planning and public messaging in injury prevention.[10,18]

Self-inflicted injuries and assaults among young people are also an important public health concern. Self-inflicted injuries are used as a proxy for suicide attempts, and the high rate of hospitalizations associated with self-inflicted injuries among 15–24 year olds warrants further research. The group showing the highest rate of hospitalizations associated with assault were aged 20–24 years. These facts highlight the opportunity for prevention efforts among youth and young adults.[19,20]

Limitations

The population of Quebec constitutes 22.6% of the Canadian population.[16] Our

TABLE 1
Counts and rates (per 100 000) of leading causes of all hospitalizations, by sex and age group, Canada (Quebec excluded), 2018/19

Rank	All ages[a] n (rate per 100 000)			Age groups n (rate per 100 000)									
	All sexes[b]	Male	Female	<1	1–9	10–14	15–19	20–24	25–34	35–44	45–64	65–79	80+
1	Examination, specific care, potential hazards and reproduction-related circumstances	Circulatory system diseases	Pregnancy, childbirth and the puerperium	Examination, specific care, potential hazards and reproduction-related circumstances	Respiratory system diseases	Mental and behavioural disorders	Mental and behavioural disorders	Pregnancy, childbirth and the puerperium	Pregnancy, childbirth and the puerpe-rium	Pregnancy, childbirth and the puerperium	Circulatory system diseases	Circulatory system diseases	Circulatory system diseases
	322 393 (1118.6)	167 538 (1171.7)	303 560 (2090.3)	192 431 (64 337.8)	19 943 (716.4)	6586 (418.5)	15 373 (903.9)	32 423 (3487.3)[c]	190 039 (9518.3)[c]	73 664 (3831.2)[c]	75 501 (965.1)	107 681 (2975.6)	85 913 (7115.3)
2	Pregnancy, childbirth and the puerperium	Examination, specific care, potential hazards and reproduction-related circumstances	Examination, specific care, potential hazards and reproduction-related circumstances	Conditions originating from perinatal period	Unintentional injuries[d]	Digestive system diseases	Digestive system diseases	Mental and behavioural disorders	Digestive system diseases	Digestive system diseases	Digestive system diseases	Musculoskeletal and connective tissue diseases	Respiratory system diseases
	303 560[e]	150 99 (1056.0)	171 260 (1179.3)	102 599 (34 303.2)	5952 (213.8)	4209 (267.5)	6488 (381.5)	9763 (500.7)	20 039 (492.3)	24 147 (636.4)	74 904 (957.5)	68 017 (1879.6)	51 547 (4269.1)
3	Circulatory system diseases	Digestive system diseases	Circulatory system diseases	Congenital anomalies	Symptoms, signs and findings not elsewhere classified	Unintentional injuries[d]	Pregnancy, childbirth and the puerperium	Digestive system diseases	Mental and behavioural disorders	Mental and behavioural disorders	Musculoskeletal and connective tissue diseases	Digestive system diseases	Unintentional injuries[d]
	285 321 (990.0)	120 747 (844.4)	117 778 (811.0)	12 610 (4216.1)	5038 (181.0)	2761 (175.4)	6423 (777.1)[c]	7665 (393.1)	19 000 (466.8)	15 854 (417.8)	53 156 (679.5)	59 809 (1652.8)	38 928 (3224.0)
4	Digestive system diseases	Respiratory system diseases	Digestive system diseases	Respiratory system diseases	Infectious and parasitic diseases	Respiratory system diseases	Unintentional injuries[d]	Unintentional injuries[d]	Examination, specific care, potential hazards and reproduction-related circumstances	Genitourinary system diseases	Neoplasms	Respiratory system diseases	Digestive system diseases
	238 438 (827.3)	102 745 (718.5)	117 676 (810.3)	9660 (3229.7)	4799 (172.4)	2045 (130.0)	3720 (218.7)	4434 (227.4)	15 443 (379.4)	13 865 (365.4)	51 417 (657.3)	58 004 (1602.9)	35 240 (2918.6)
5	Respiratory system diseases	Musculoskeletal and connective tissue diseases	Respiratory system diseases	Symptoms, signs and findings not elsewhere classified	Nervous system diseases	Symptoms, signs and findings not elsewhere classified	Symptoms, signs and findings not elsewhere classified	Examination, specific care, potential hazards and reproduction-related circumstances	Unintentional injuries[d]	Neoplasms	Respiratory system diseases	Neoplasms	Symptoms, signs and findings not elsewhere classified
	196 240 (680.9)	71 957 (503.2)	93 488 (643.8)	4659 (1557.7)	4605 (165.4)	1822 (115.8)	2570 (151.1)	4426 (227.0)	9319 (228.9)	9957 (262.4)	38 351 (490.2)	54 070 (1494.2)	31 679 (2623.7)
6	Musculoskeletal and connective tissue diseases	Neoplasms	Musculoskeletal and connective tissue diseases	Infectious and parasitic diseases	Digestive system diseases	Examination, specific care, potential hazards and reproduction-related circumstances	Examination, specific care, potential hazards and reproduction-related circumstances	Symptoms, signs and findings not elsewhere classified	Genitourinary system diseases	Examination, specific care, potential hazards and reproduction-related circumstances	Genitourinary system diseases	Genitourinary system diseases	Examination, specific care, potential hazards and reproduc-tion-related circumstances
	159 473 (553.3)	68 840 (481.4)	87 514 (602.6)	2583 (863.6)	4480 (160.9)	1524 (96.8)	2303 (135.4)	2536 (130.1)	7338 (180.3)	9096 (239.7)	35 493 (453.7)	37 379 (1032.9)	30 807 (2,551.4)

Continued on the following page

Rank	All ages[a] n (rate per 100 000)			Age groups n (rate per 100 000)									
	All sexes[b]	Male	Female	<1	1–9	10–14	15–19	20–24	25–34	35–44	45–64	65–79	80+
7	Neoplasms	Unintentional injuries[d]	Neoplasms	Genitourinary system diseases	Examination, specific care, potential hazards and reproduction-related circumstances	Nervous system diseases	Respiratory system diseases	Respiratory system diseases	Symptoms, signs and findings not elsewhere classified	Unintentional injuries[d]	Symptoms, signs and findings not elsewhere classified	Examination, specific care, potential hazards and reproduction-related circumstances	Genitourinary system diseases
	144 396 (501.0)	63 049 (440.9)	75 551 (520.3)	1702 (569.1)	2979 (107.0)	1346 (85.5)	2232 (131.2)	2407 (123.5)	5870 (144.2)	8792 (231.7)	28 568 (365.2)	35 011 (967.5)	26 161 (2,166.7)
8	Unintentional injuries[d]	Mental and behavioural disorders	Genitourinary system diseases	Digestive system diseases	Congenital anomalies	Musculoskeletal and connective tissue diseases	Genitourinary system diseases	Genitourinary system diseases	Respiratory system diseases	Circulatory system diseases	Examination, specific care, potential hazards and reproduction-related circumstances	Symptoms, signs and findings not elsewhere classified	Musculoskeletal and connective tissue diseases
	131 366 (455.8)	62 664 (438.2)	73 754 (507.9)	1457 (487.1)	2411 (86.6)	1341 (85.2)	1741 (102.4)	2278 (116.8)	5235 (128.6)	8706 (229.4)	28 373 (362.7)	33 864 (935.8)	23 160 (1918.1)
9	Genitourinary system diseases	Symptoms, signs and findings not elsewhere classified	Unintentional injuries[d]	Nervous system diseases	Genitourinary system diseases	Endocrine, nutritional and metabolic diseases	Self-inflicted injuries	Endocrine, nutritional and metabolic diseases	Endocrine, nutritional and metabolic diseases	Symptoms, signs and findings not elsewhere classified	Unintentional injuries[d]	Unintentional injuries[d]	Neoplasms
	128 670 (446.4)	60 851 (425.6)	68 309 (470.4)	997 (333.3)	1877 (67.4)	1237 (78.6)	1714 (100.8)	2052 (105.2)	4909 (120.6)	7367 (194.2)	27 435 (350.7)	29 178 (806.3)	20 848 (1726.6)
10	Symptoms, signs and findings not elsewhere classified	Conditions originating from perinatal period	Symptoms, signs and findings not elsewhere classified	Skin and subcutaneous tissue diseases	Diseases of blood and blood-forming organs and certain disorders involving the immune mechanism	Genitourinary system diseases	Endocrine, nutritional and metabolic diseases	Self-inflicted injuries	Neoplasms	Respiratory system diseases	Mental and behavioural disorders	Infectious and parasitic diseases	Infectious and parasitic diseases
	123 974 (430.2)	55 873 (390.7)	63 119 (434.6)	853 (285.2)	1834 (65.9)	836 (53.1)	1662 (97.7)	1397 (71.7)	4188 (102.9)	6816 (179.6)	26 592 (339.9)	18 299 (505.7)	15 893 (1316.3)
ALL	2 587 663 (8978.3)	1 147 083 (8021.9)	1 440 264 (9917.8)	332 876 (111 294.4)	64 141 (2304.0)	28 918 (1837.6)	52 729 (3100.5)	78 896 (4046.3)	305 816 (7513.1)	210 494 (5547.3)	525 265 (6714.4)	577 323 (15 953.6)	411 203 (34 055.9)

Data source: Discharge Abstract database 2018/19 (Canadian Institute for Health Information).

Notes: ICD-10-CA codes for defining the causes: A00.0–B99 (infectious and parasitic diseases); C00.0–D48.9 (neoplasms); D50–D89 (diseases of blood and blood-forming organs and certain disorders involving the immune mechanism; E00.0–E90 (endocrine, nutritional and metabolic diseases); F00.0–F99 (mental and behavioural disorders); G00.0–G99.8 (nervous system diseases); I00–I99 (circulatory system diseases); J00–J99.8 (respiratory system diseases); K00.0–K93.8 (digestive system diseases); L00–L99.8 (skin and subcutaneous tissue diseases); M00.0–M99.9 (musculoskeletal and connective tissue diseases); N00.0–N99.9 (genitourinary system diseases); O00.0–O99.8 (pregnancy, childbirth and the puerperium); P00.0–P96.9 (conditions originating from perinatal period); Q00.0–Q99.9 (congenital anomalies); R00.0–R99 (symptoms, signs and findings not elsewhere classified); Z00.0–Z99.9 (examination, specific care, potential hazards and reproduction-related circumstances); S00.0–T98.3 and V01.0–X59.9, Y85.0–Y86 (unintentional injuries); S00.0–T98.3 and X60–X84, Y87.0 (self-inflicted injuries); S00.0–T98.3 and X85–Y09, Y87.1 (assault); S00.0–T98.3 and Y10–Y34, Y87.2 (injuries with undetermined intent); S00.0–T98.3 and Y35.0–Y84.9, Y88.0–Y89.9 (other injuries).

Shading indicates data related to injuries.

[a] All ages include those whose age was unknown (2 records for all causes).

[b] All sexes include males, females and other sexes (316 records for all causes).

[c] The rate is based on female population only.

[d] Unintentional injuries do not include complications of medical and surgical care.

[e] A rate is not applicable.

TABLE 2
Counts and rates (per 100 000) of leading causes of injury hospitalizations, by sex and age group, Canada (Quebec excluded), 2018/19

	All ages n (rate per 100 000)			Age groups n (rate per 100 000)									
	All sexes[a]	Males	Females	<1	1–9	10–14	15–19	20–24	25–34	35–44	45–64	65–79	80+
All injuries (excluding complications of medical and surgical care)[b]	225 208 (781.4)	111 108 (777.0)	114 072 (785.5)	1479 (494.5)	6977 (250.6)	4235 (269.1)	7935 (466.6)	8561 (439.1)	16 327 (401.1)	15 099 (397.9)	45 683 (584.0)	50 600 (1398.3)	68 312 (5657.6)
Unintentional injuries (excluding complications of medical and surgical care)[b]	203 600 (706.4)	100 318 (701.6)	103 268 (711.1)	1418 (474.1)	6876 (247.0)	3171 (201.5)	4460 (262.3)	5536 (283.9)	12 072 (296.6)	11 902 (313.7)	40 849 (522.2)	49 440 (1366.2)	67 876 (5621.5)
Falls	116 318 (403.6)	47 113 (329.5)	69 202 (476.5)	389 (130.1)	3246 (116.6)	1201 (76.3)	993 (58.4)	1288 (66.1)	3127 (76.8)	3839 (101.2)	19 631 (251.0)	32 145 (888.3)	50 459 (4179.0)
Suffocation	27 182 (94.3)	16 625 (116.3)	10 554 (72.7)	196 (65.5)	509 (18.3)	126 (8.0)	176 (10.3)	350 (18.0)	872 (21.4)	979 (25.8)	4852 (62.0)	7684 (212.3)	11 438 (947.3)
Motor vehicle traffic crashes	12 718 (44.1)	7777 (54.4)	4940 (34.0)	15 (5.0)[e]	212 (7.6)	175 (11.1)	788 (46.3)	1178 (60.4)	1936 (47.6)	1554 (41.0)	3641 (46.5)	2106 (58.2)	1113 (92.2)
Poisonings	9770 (33.9)	5191 (36.3)	4576 (31.5)	80 (26.7)	501 (18.0)	120 (7.6)	478 (28.1)	643 (33.0)	1572 (38.6)	1322 (34.8)	2818 (36.0)	1464 (40.5)	772 (63.9)
Struck by/against	5054 (17.5)	3655 (25.6)	1399 (9.6)	26 (8.7)[e]	325 (11.7)	411 (26.1)	531 (31.2)	340 (17.4)	675 (16.6)	536 (14.1)	1077 (13.8)	581 (16.1)	552 (45.7)
Fire/hot object/smoke	1889 (6.5)	1216 (8.5)	671 (4.6)	55 (18.4)	307 (11.0)	43 (2.7)	37 (2.2)	106 (5.4)	188 (4.6)	174 (4.6)	536 (6.9)	326 (9.0)	117 (9.7)
Self-inflicted	13 661 (47.4)	4925 (34.4)	8723 (60.1)	0 (0)	5 ([c])	921 (58.5)	2842 (167.1)	1931 (99.0)	2201 (54.1)	1762 (46.4)	3011 (38.5)	754 (20.8)	234 (19.4)
Assault	6509 (22.6)	5046 (35.3)	1462 (10.1)	75 (25.1)	82 (2.9)	81 (5.1)	504 (29.6)	976 (50.1)	1793 (44.0)	1214 (32.0)	1368 (17.5)	260 (7.2)	156 (12.9)
Undetermined intent	2809 (9.7)	1573 (11.0)	1236 (8.5)	7 ([c])	27 (1.0)[e]	88 (5.6)	226 (13.3)	281 (14.4)	502 (12.3)	440 (11.6)	831 (10.6)	288 (8.0)	119 (9.9)
Legal intervention / war	113 (0.4)	97 (0.7)	16 (0.1)[e]	–[d]	–[d]	–[d]	–[d]	10 (0.5)[e]	36 (0.9)[e]	24 (0.6)[e]	38 (0.5)	–[d]	–[d]

Data source: Discharge Abstract database 2018/19 (Canadian Institute for Health Information).

Note: ICD-10-CA codes for the injury groups: V01.0–Y36.9, Y85.0–Y87.2, Y89(.0–.9) (all injuries); V01.0–X59.9, Y85.0–Y86 (unintentional injuries); W00–W19 (falls); W75–W84 (suffocation); X40–X49 (poisonings); V02–V04(.1), V02–V04(.9), V09.2, V12–V14(.3–.9), V19(.4–.6), V20–V28(.3–.9), V29(.4–.9), V30–V79(.4–.9), V80(.3–.5), V81–V82(.1), V83–V86(.0–.3), V87(.0–.8), V89.2 (motor vehicle traffic crashes); W20–W22, W50–W52 (struck by/against); X00–X19 (fire/hot object/smoke); X60–X84, Y87.0 (self-inflicted injuries); X85–Y09, Y87.1 (assault); Y10–Y34, Y87.2, Y89.9 (undetermined intent); Y35.0–Y36.9, Y89(.0–.1) (legal intervention/war).

[a] All sexes include males, females and other sexes (28 records for all injuries).

[b] ICD-10 codes for complications of medical and surgical care: Y40–Y84, Y88.

[c] The rate is not reliable.

[d] The cell count is less than 5.

[e] The rate should be interpreted with caution.

data source was the DAD from CIHI, which does not include Quebec hospitalization data. The Quebec Ministry of Health and Social Services provided hospitalization statistics by sex (no age group breakdown) through MED-ÉCHO,[21] while our analyses require micro-level data.

Second, to compare the burden of injuries with other diseases and conditions, we used both MRD (S, T codes) and external cause codes to identify injury cases. This method classifies records whose external cause was the underlying cause for their non-injury MRD into non-injury cases. Therefore, it undercounts the injury cases. It also indicates that we should not expect the equal numbers of unintentional, self-inflicted and other injuries between Table 1 and 2.

In addition, the method of data analysis can affect ranking. To accurately monitor the trend in injury hospitalizations, consistent case definitions and procedures to compile and report data are necessary. We aim to do more work in this area.

Conclusion

Overall, unintentional injuries were the eighth leading cause of hospitalization among all causes. For unintentional injury-related hospitalizations, in rank order, the leading causes were falls, suffocation, MVT, poisonings, struck by/against, and fire/hot object/smoke. However, the rankings were different across age groups. The updated injury hospitalization information is critical for understanding the burden and pattern of injuries in Canada.

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Conflicts of interest

All authors declare no conflicts of interest.

Authors' contributions and statement

All authors have read and approved of the content of this article. XY was involved in conceptualization, data analysis, interpretation and manuscript preparation. RS, SM and WT were involved in conceptualization, data interpretation and manuscript preparation.

The content and views expressed in this article are those of the authors and do not necessarily reflect those of the Government of Canada.

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At-a-glance

The Canadian Bikeway Comfort and Safety (Can-BICS) Classification System: a common naming convention for cycling infrastructure

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Abstract

There is no standard naming convention for cycling infrastructure across cities. Our aim was to develop a common nomenclature for cycling infrastructure in Canada, relevant to the context of public health practice. We drew on transportation engineering design guides and public health guidance to develop a bicycle facility classification system: the Canadian Bikeway Comfort and Safety (Can-BICS) classification system, a three-tiered classification scheme that groups five bicycle facilities based on safety performance and user comfort. Adopting consistent nomenclature as per the Can-BICS system will support regional and national surveillance efforts in public health, planning and sustainability.

Keywords: *open data, active transportation, cycling, infrastructure, nomenclature*

Highlights

- A common nomenclature for cycling infrastructure in Canada is needed to further public health surveillance efforts on active-transportation environments.
- The Can-BICS system is a three-tiered cycling infrastructure classification system that reflects the safety performance and user comfort of five bicycle facility types.
- High-comfort bikeways are low-stress routes. These bikeways include cycle tracks on major streets, local street bikeways and cycle-only off-street paths.
- Medium-comfort bikeways are low-to-medium stress routes. These bikeways include multi-use paths sited next to a roadway or along independent corridors.
- Low-comfort bikeways are high-stress routes. These bikeways include painted bike lanes along busy roadways.

Introduction

Getting more people to cycle, more often, is a goal common to public health, sustainability and transportation agendas.[1-4] Many cities assemble data on their cycling infrastructure and increasingly make these data publicly available through open data initiatives; however, there is no standard naming convention to describe cycling infrastructure. This lack of common nomenclature hinders research and practice efforts to understand the role of cycling infrastructure in supporting active travel across communities.

Our aim was to develop a common nomenclature for cycling infrastructure in Canada, relevant to the context of public health. Such nomenclature is a foundational step toward the operationalization of metrics that may be used for public health research and surveillance of physical activity in Canada.[5] We considered cycling infrastructure to be part of roadways or paths intended for cycling (also referred to as “bicycle facilities” or “bikeways”); we did not include end-of-trip facilities such as cycle parking, lockers or showers, which are not consistently tracked.

This study is exempt from Research Ethics Board review as the research uses exclusively publicly available information for which there is no reasonable expectation of privacy.

Methods

Overview

We reviewed transportation engineering design guides and used public health guidance to develop a classification system based on safety performance (injury or crash risk along different infrastructure types) and user comfort (preferences for infrastructure types in terms of comfort and stress). We also compiled cycling infrastructure names used in open data from Canadian municipalities and mapped them onto the nomenclature classification system.

Engineering design guide review

We reviewed national transportation engineering design guides from Canada and the USA published within the last 5 years

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to identify how cycling infrastructure types are defined and categorized. From these we identified other relevant documents. The documents reviewed were as follows: the Transportation Association of Canada (TAC) *Geometric Design Guide for Canadian Roads*[6]; the City of Vancouver *Transportation Design Guidelines: All Ages and Abilities Cycling Routes*[7]; CROW *Design Manual for Bicycle Traffic*[8]; NACTO's *Urban Bikeway Design Guide*[9] and *Designing for All Ages & Abilities: Contextual Guidance for High-Comfort Bicycle Facilities*[10]; and the Massachusetts Department of Transportation *Separated Bike Lane Planning & Design Guide*[11].

Developing classification

We analyzed the classification approaches and justification within each of the engineering guidelines to inform our proposed nomenclature. We also reviewed the public health literature on safety and preference for cycling infrastructure types because safety performance and user comfort were primary organizing principles for the classification scheme (for more information, see the review in *The Canadian Bikeway Comfort and Safety (Can-BICS) Classification System: A Proposal for Developing Common Naming Conventions for Cycling Infrastructure* report[12]). Our preliminary classification scheme was reviewed by one US and three Canadian experts in the fields of public health (n = 2) and transportation planning and design (n = 2). Their feedback resulted in refined infrastructure definitions but no substantial changes to the classification.

Open data analysis

Our aim was to characterize the range of cycling infrastructure names used by Canadian communities to understand the scope of the nomenclature and how this interfaced with the proposed Can-BICS scheme. To select a national sample, we chose the 10% most populated census subdivisions from each province and territory. Taken together, these 45 census subdivisions covered 50.4% of the Canadian population.

We searched for a cycling infrastructure dataset and supplemented open data with a municipal cycling map when necessary. We extracted all names used in the municipal data and categorized these to the Can-BICS classification scheme. First, where possible (~60% of names), we categorized facility names to the five Can-BICS cycling facilities by name alone (e.g. bike lanes categorized as painted bike lane). To ensure rigour, we performed spot checks on 10% of these facility names by using Google Street View (an online street view imagery service) and QGIS (a geographic information system) to locate and identify infrastructure types; all matched. Where the name itself did not facilitate easy categorization (~40%), we relied on Google Street View and QGIS. The open data files and facility name data are available through the SFU RADAR repository (researchdata.sfu.ca).

Results

The six engineering design guidelines identified multiple cycling facilities. We grouped these into five consolidated categories ("painted bike lanes," "local street bikeways," "cycle tracks," "bike paths" and "multi-use paths") related to design, exclusivity for cyclists and proximity of cyclists to other road users.[6,7] Some guides touched on safety (e.g. separation from motor vehicles), but there was little explicit consideration of user preference or comfort, especially for roadway cycling facilities.

Integrating practice guidelines and public health considerations to categorize infrastructure that would best encourage cycling and make cycling safer, we developed the Canadian Bikeway Comfort and Safety (Can-BICS) classification system. This three-tiered classification scheme groups five cycling facilities based on safety performance and user comfort (Table 1):

- ***High-comfort bikeways.*** These low-stress cycling facilities are comfortable for most people. Route types include cycle tracks alongside busy roads, local street bikeways and off-road bike paths.
- ***Medium-comfort bikeways.*** These low-to-medium stress cycling facilities are considered comfortable by some people. The off-road infrastructure multi-use path fits within this category. Multi-use paths are shared with pedestrians and other active modes and can be located along a road or in an independent corridor.
- ***Low-comfort bikeways.*** These cycling facilities are high stress and comfortable for few people. The infrastructure type within this category is a painted bike lane, where people are cycling in a painted lane along busy roadways.

Comparing open data facility names with Can-BICS

Of the 45 municipalities, 89% (n = 40/45) had an open data catalogue and 80% of these included a cycling infrastructure dataset (n = 32/40). Data sources were published between 2005 and 2019. We extracted 269 cycling infrastructure names from open data (range: 2–14 per census subdivision) after removing obvious pedestrian infrastructure (e.g. stairs and sidewalks), route fragments and decommissioned routes. About 100 unique names were in use, after taking into account related terms (e.g. bike lane and bicycle lane). We categorized 60% of the 269 names to the five Can-BICS cycling facilities by name alone (e.g. bike lanes categorized as painted bike lane). The remaining 40% (n = 108) we assessed via Google Maps Street View (see The Canadian Bikeway Comfort and Safety (Can-BICS) Classification System: A Proposal for Developing Common Naming Conventions for Cycling Infrastructure).[12]

We compared municipal open data nomenclature and Can-BICS (Figure 1) to assess overlap. Note that the proportions reported here represent the frequency of use of this facility name across the open data files and not the proportional distance of an infrastructure type within the cycling network. We found that 23% of names in open data were high-comfort bikeways: 8% being cycle tracks, 12% local street bikeways and 3% bike paths. Overall, 24% were medium comfort (multi-use paths) and 28% were low comfort (painted bike lanes).

There were also facility names that arose in open data but did not fit the Can-BICS criteria as they are not considered suitable (i.e. safe or comfortable) for promoting cycling for people of all ages and abilities based on the current state of knowledge. Many were shared lanes, that is, sharrows in a car travel lane. There is no evidence that sharrows provide the benefit of safety, and the majority of people do not want to share a travel lane with motor vehicles. Others were gravel trails, namely multi-use trails surfaced in gravel, dirt or aggregate, including mountain bike trails, walking trails in parks or hiking dirt paths. The Transportation Association of Canada guidelines explicitly exclude gravel trails, with the rationale that these are accessible to a smaller range of bicycles and have unique design requirements.[6] Finally, "mixed

TABLE 1
The Canadian Bikeway Comfort and Safety (Can-BICS) Classification System

High-comfort bikeways: Comfortable for most people		
Facility	**Description**	**Image**
Cycle track	A roadway lane exclusively for cyclists and physically separated from both motor vehicles and the sidewalk. Separation from motor vehicle traffic must include a vertical barrier (e.g. a raised median, bollards, box planters or trees and landscaping). Separation from the sidewalk may include street furniture, a curb or landscaped buffer. Facility may be at the level of the roadway or the sidewalk or between the two.	 
Local street bikeway	A local street (no centre line or lanes) where cyclists share the roadway with motor vehicles. Traffic-calming elements limit motor vehicle speeds and volumes and inhibit their through travel. Bicycle priority measures facilitate cyclists' safe crossing of streets and limit stops and delays. The facility includes measures to improve cyclist comfort: smooth surfaces; street lighting; wayfinding signage and pavement markings; and consistent paving material and colour.	 
Bike path	An off-road paved path exclusively for cyclists located along independent corridors away from a road. May be one-way or two-way with a centre line. Often adjacent to a walking path and separated by a painted line, curb or landscaped buffer.	 

Continued on the following page

Medium-comfort bikeways: Comfortable for some people		
Facility	**Description**	**Image**
Multi-use path	A two-way paved path shared by cyclists, pedestrians and other users (e.g. skateboarders and rollerbladers). May be located along independent corridors away from a road or next to a roadway and physically segregated from motor vehicles (replacing a sidewalk).	 
Low-comfort bikeways: Comfortable for few people		
Facility	**Description**	**Image**
Painted bike lane	A painted lane along a busy roadway that is designated by bicycle and diamond pavement markings and signs as exclusively for cyclists. The lane is positioned between a vehicle travel lane and the curb. It may be buffered using diagonal or chevron hatching or unbuffered. Includes both advisory bike lanes (marked by broken lane lines) on the edge of roadways too narrow to provide exclusive cycling and driving spaces and bicycle accessible paved shoulders (indicated by an edge line and bike route signs or stencil markings) on roads without a curb.	 

Source: The Canadian Bikeway Comfort and Safety (Can-BICS) Classification System: A Proposal for Developing Common Naming Conventions for Cycling Infrastructure.[12]

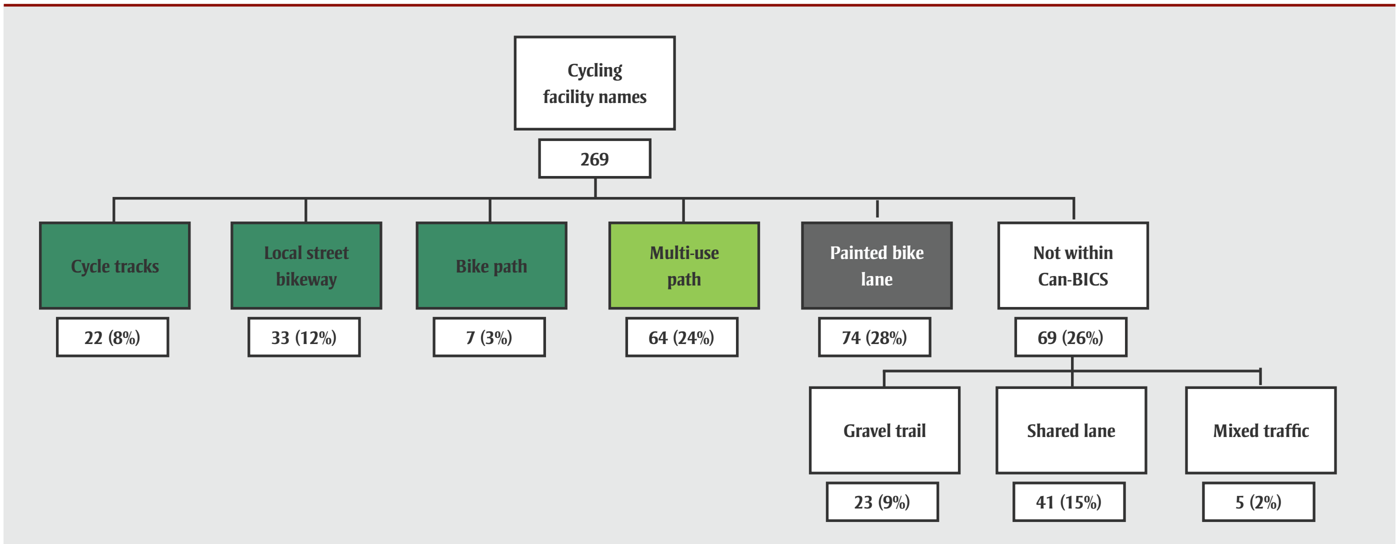
traffic" infrastructure (unimproved local roads) may serve as links to the main cycling network, but without signage or traffic calming, do not constitute cycling infrastructure. Together, these routes comprised 26% of the different facility names in open data.

Discussion

The Canadian Bikeway Comfort and Safety (Can-BICS) classification system defines five types of cycling facilities ordered into a three-tiered classification scheme based on safety performance and user comfort. The classification was informed by a review of professional practice guidelines for bicycle facility design, public health literature on safety and preferences and a scan of current naming conventions. This approach focuses on safer cycling facility types preferred by people of all ages and abilities, reflecting a public health perspective that aims to get more people cycling, more often, for both individual and population-level benefits.[13]

A standardized nomenclature approach for cycling infrastructure is essential for public health surveillance as it can enable comparisons of the availability and infrastructure types across settings and over time. We envision that planners can apply the standardized nomenclature in Can-BICS to categorize the routes in their own communities and enable the development

FIGURE 1
Categorization of municipal open data bicycle facility names[a] to the Can-BICS classification system



Source: The Canadian Bikeway Comfort and Safety (Can-BICS) Classification System: A Proposal for Developing Common Naming Conventions for Cycling Infrastructure.[12]
Abbreviation: Can-BICS, Canadian Bikeway Comfort and Safety.
[a] 269 facility names from across 45 census subdivisions.

of granular spatial data and metrics to support local public health authorities.

For Can-BICS, next steps are to operationalize metrics (e.g. kilometres of high/medium/low-comfort routes per area), identify spatial units (e.g. dissemination area) and boundary issues, and evaluate the quality of open data sources. Emerging work suggests OpenStreetMap (OSM; openstreetmap.org) is a promising data source for Canadian cities.[14] For a national effort, any data source must be evaluated in terms of access, completeness and comparability, but the potential to streamline and standardize efforts is strong.

Strengths and limitations

Design matters. While Can-BICS uses a broad classification of user comfort and safety, there are nuances. A cycle track (high comfort) that is poorly designed may have greater injury risk than a well-designed painted bike lane (low comfort). Intersection treatments and network connectivity also impact route safety and comfort.

Conclusion

There is limited past work in harmonizing the names for cycling infrastructure across cities, although this is important for comparing neighbourhoods within a single city or a set of cities as part of a national approach.[15,16] A standardized nomenclature such as Can-BICS is a foundational step toward building capacity in public health surveillance for urban cycling environments.

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Authors' contributions and statement

MW led the project conceptualization, supervised the analysis and contributed to the drafting and revision of the paper. MZ led the literature review, data collection and data analysis and contributed to the drafting and revision of paper. GB contributed to the project conceptualization and the drafting and revision of the paper

The content and views expressed in this article are those of the authors and do not necessarily reflect those of the Government of Canada.

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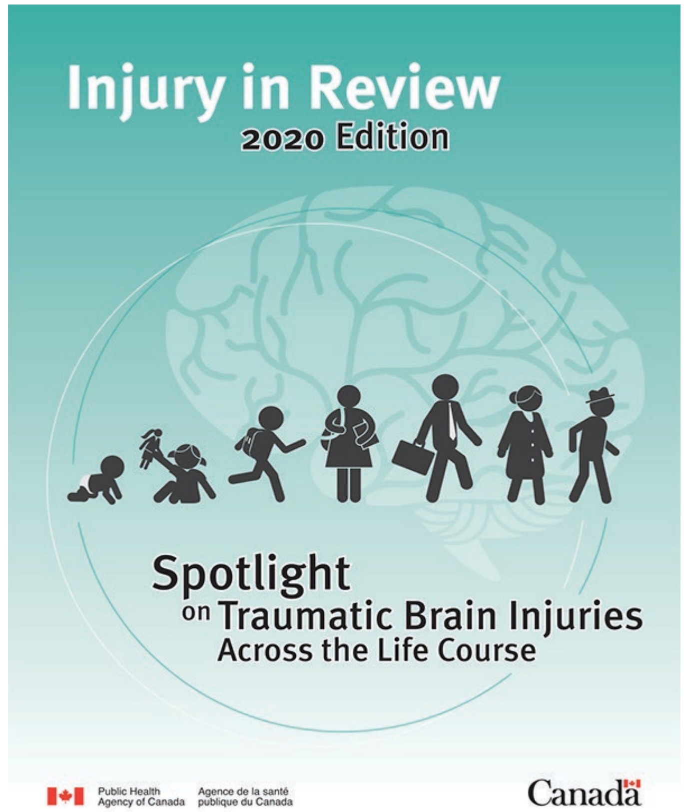

Injury in Review, 2020 Edition: Spotlight on Traumatic Brain Injuries Across the Life Course was released on August 7, 2020.

This report, the third edition of the Public Health Agency of Canada's (PHAC) *Injury in Review* series, provides important national surveillance statistics on the causes of traumatic brain injuries (TBI) across the life course, including sports, seniors' falls, assaults, consumer products, and more.

The following statistics are reported:

- Deaths, from Statistics Canada's Vital Statistics: Deaths database;
- Hospitalizations, from the Canadian Institute of Health Information's (CIHI) Hospital Morbidity Database (HMDB) and Discharge Abstract Database (DAD);
- Emergency department (ED) visits for select jurisdictions, from CIHI's National Ambulatory Care Reporting System (NACRS);
- Sentinel surveillance of emergency department visits, from PHAC's Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP).

Highlights from the publication

Deaths

- Between 2002 and 2016, there were approximately 235 471 injury deaths, 53 200 (22.6%) of which were associated with a TBI diagnosis. TBI mortality rates rose sharply among those aged 65 years and older, and were highest for the oldest Canadians.
- Between 2002 and 2016, rates for males decreased slightly, while female rates increased slightly. Some of the leading causes of TBI deaths were transportation collisions, falls among seniors and suicide among males.

Hospitalizations

- Between 2006/07 and 2017/18, there were 399 376 hospitalizations for head injuries, 63% (251 504) of which involved males. Over this period, a slight increase was observed in head injury hospitalization rates in females, while a slight decrease was observed for rates in males. Falls were the leading cause of hospitalization for a head injury.

ED visits

- Between 2002/03 and 2017/18, 5 074 239 ED visits for head injuries were recorded in Ontario and Alberta combined. For both males and females, the number of TBI ED visits has been increasing since 2009/10. Falls and sports and recreation incidents are the leading causes of ED visits for a TBI.

Sentinel surveillance of ED visits

- Sentinel surveillance of TBIs shows similar patterns to those reported from other sources.
- An increasing trend in TBIs was observed in both males and females between 1990 and 2018.

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