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Association of frailty and pre-frailty with increased risk of mortality among older Canadians

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ABSTRACT

Background

Frailty is a complex syndrome that is associated with aging but not synonymous with the normal aging process. It has been associated with all-cause mortality, but less is known about frailty and mortality from specific causes.

Data and methods

Data from the 2013 and 2014 Canadian Community Health Survey (CCHS) linked to the Canadian Vital Statistics - Death Database were used to estimate the prevalence of frailty among Canadians aged 65 or older. Levels of frailty were based on validated cut-points for the 30-item frailty index. The relationship of frailty to mortality risk during the period of three to five years following the CCHS interview was assessed with Cox proportional hazards models adjusted for sociodemographic factors and health behaviours. Associations between frailty and mortality from neoplasms, circulatory diseases and disease of the respiratory system were examined in separate models.

Results

An estimated 1.1 million (22%) community-dwelling older adults were frail in 2013 and 2014, and another 1.6 million (32%) were considered pre-frail. Frailty was more common among females than males and among those in older age groups. The risk of mortality increased significantly with increasing levels of frailty, even after accounting for sociodemographic factors and health behaviours. This was the case for all-cause mortality, as well as for death from three major underlying causes—neoplasms, and diseases of the circulatory and respiratory systems.

Interpretation

Even individuals who were classified as pre-frail had an increased risk of mortality overall and from three leading causes compared with those who were robust, demonstrating the importance of screening community-dwelling older adults for frailty.

Keywords

aging, death, mortality, population study, probabilistic linkage

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What is already known on this subject?

- Frailty is a complex syndrome that is associated with aging but not synonymous with the normal aging process. It is characterized by a state of increased vulnerability resulting from an accumulation of age- or disease-associated decrements.
- There is a health-survival paradox—females are more likely than males to be frail, but males who are frail are more likely to die than females who are frail.
- The association between frailty and all-cause mortality is well established, but few studies have examined frailty in association with cause-specific mortality.

What does this study add?

- In 2013 and 2014, an estimated 22% of community-dwelling older Canadians were frail, similar to the proportion reported 20 years earlier in another Canadian study. An additional 32% were considered pre-frail.
- Greater levels of frailty were associated with a higher risk of all-cause mortality and death from three major underlying causes: neoplasms, and diseases of the circulatory and respiratory systems.
- Even older adults who were classified as pre-frail—i.e., having a slightly elevated score on the frailty index that was nevertheless below the threshold for frailty—had a higher risk of mortality from each of these causes than those classified as robust.

Frailty is a complex syndrome that involves multiple body systems – older adults who are frail typically experience a state of increased vulnerability resulting from an accumulation of age- or disease-associated decrements.¹ There is an accelerated loss of physiological reserves, which lowers resistance to stressors and—subsequently—the ability of frail individuals to avoid and recover from illness or trauma.² Frailty is increasingly common at older ages but is not synonymous with the aging process, as the health status of individuals of the same age can differ dramatically.³

Frailty threatens older adults' independence and their ability to “age in place,” i.e., to remain in their home and community of choice for as long as they wish.^{4,5} The risk of adverse outcomes such as falls, fractures, premature morbidity and death increases with frailty, as does the demand for health care resources, including hospitals and long-term care facilities.⁶⁻¹⁰ Beyond the threat to an individual's quality of life, frailty—and its associated dependencies—can impact family members and other informal caregivers.^{4,11}

While there is generally agreement on the concept of frailty, the same is not true for the detection and measurement of this condition.¹²⁻¹⁴ There are two main approaches to measuring frailty.¹¹ The first is a phenotype approach, which classifies individuals using a biologic syndrome model, whereby those with at least three of five physical components (unintentional weight loss, self-reported exhaustion, poor grip strength, slow walking speed and low physical activity) are categorized as frail.⁷ The second approach, and the one on which this study is based, is the frailty index (FI), which assesses accumulated health deficits over the life course and includes symptoms, chronic conditions and disability. The higher an individual's

ratio of deficits present to the number of deficits considered, the more likely they are to be considered frail.¹⁵⁻¹⁷ A broad selection of concepts is included in this approach, with the number of deficits typically ranging from 30 to 75.¹⁶ Both approaches have been used in epidemiological research and clinical practice, but prevalence estimates are typically higher with the accumulation of deficits approach than with the phenotype approach.^{2,18}

Monitoring frailty among older adults is increasingly important with Canada's rapidly aging population. The proportion of Canadians aged 65 or older is projected to increase from 17.5% in 2019 to between 21.4% and 29.5% by 2068.¹⁹ Although the association between frailty and all-cause mortality is well established,^{9,18} less is known about specific causes of mortality.²⁰⁻²¹ This study estimates the prevalence of frailty and pre-frailty among adults aged 65 or older in Canada, and examines associations with mortality—all-cause and cause-specific (i.e., neoplasms, and diseases of the circulatory and respiratory systems)—over a follow-up period of three to five years. Sex differences in frailty and mortality are highlighted.

Methods

Data sources

Canadian Community Health Survey 2013 and 2014

The cross-sectional Canadian Community Health Survey (CCHS) 2013 and 2014 collected information on health status, health care use and health determinants for the population living in private households (i.e., non-institutionalized) who were aged 12 or older in all provinces and territories. The survey

excludes full-time members of the Canadian Armed Forces, and residents of First Nations reserves and certain remote regions. Altogether, these exclusions represent less than 3% of the target population. Data were collected from January to December each year. The response rate was 66.2%. Detailed documentation for the CCHS is available at <https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&Id=144170>.

The Canadian Vital Statistics - Death Database

The Canadian Vital Statistics – Death Database (CVSD) is an administrative dataset that includes demographic and cause-of-death information for deaths that occur in Canada. Data are collected annually from provincial and territorial vital statistics registries. Deaths that occurred from January 2013 to December 2017, and were linked to CCHS records, were used in this analysis. Detailed documentation for the CVSD is available at <http://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&Id=1202355>.

Data linkage

Linkage approval (007-2018) was granted by the Chief Statistician of Canada and performed in accordance with the Directive on Microdata Linkage. CCHS respondents who agreed to share and link their data were probabilistically linked to the Derived Record Depository (DRD) in the Social Data Linkage Environment (SDLE) at Statistics Canada. Probabilistic record linkage works with non-unique identifiers (e.g., name, sex, date of birth and postal code) and estimates the likelihood of records referring to the same entity.²² Only employees involved in the process directly have access to the information required for linkage, and they do not have access to health- and death-related information. An analytical file without identifying information was created for this study.

Study sample

The study was based on CCHS 2013 and 2014 respondents aged 65 or older with data linked to the CVSD for those who died (Appendix Table A).²² The maximum follow-up period ranged from three to five years, from the date of a respondent's CCHS interview to December 31, 2017, or to their death—whichever came first. The study sample comprised 29,302 individuals (12,578 males, 16,724 females), 3,540 of whom (1,757 males,

1,783 females) died in the follow-up period between their CCHS interview and December 31, 2017.

Definitions

Frailty index

This study is based on the accumulation of deficits framework for the construction of a FI,¹⁵⁻¹⁷ and the operationalization and validation of the FI using CCHS variables.²³ Deficits were attributed values from 0.0 to 1.0 that corresponded to the level of each deficit (i.e., none to maximum deficit) (Appendix Table A). The sum of the values divided by the total number of deficits (30) produced FI scores ranging from 0.0 (lowest level of frailty) to 1.0 (highest level of frailty). Deficits related to functional health were derived from the eight Health Utilities Index Mark 3 domains: vision, hearing, speech, ambulation, dexterity, emotion, cognition, and pain and discomfort.²⁴ The five or six levels in each domain were rescaled to three (speech), five (emotional health, pain and discomfort, vision) or six (hearing, mobility, cognition and dexterity) equidistant, ordered scores.²³ All deficits on the FI were self-reported, including body mass index, although values were subsequently adjusted to account for the tendency of respondents to overreport height and underreport weight.²⁵

If a respondent was missing information about a deficit, the denominator was reduced by the number of missing deficits, up to a maximum of five. For example, the FI for a respondent missing information on one deficit would be based on a denominator of 29 instead of 30. The majority of records (85.2%) had complete data for all deficits comprising the FI score, 8.6% had one missing value and the remaining 6.2% had two to five missing values.

Applying previously validated cut-points,²³ continuous FI scores were classified into the following categories (Table 1).

Mortality

Mortality data were based on the underlying cause of death defined as “the disease or injury which initiated the train of morbid events leading directly or indirectly to death or the circumstances of the accident or violence which produced the fatal injury.”²⁶ These provincial and territorial data were extracted from death certificates and coded according to the

Table 1
Frailty categories

Category	Frailty index score
Not frail	0.0 to ≤ 0.21
Robust	0.0 to ≤ 0.10
Pre-frail	> 0.10 to ≤ 0.21
Frail	> 0.21
Moderately frail	> 0.21 to < 0.45
Most frail	≥ 0.45

Source: Statistics Canada, Canadian Community Health Survey, 2013 and 2014.

10th edition of the International Classification of Diseases (ICD-10). All-cause mortality reflects deaths from any underlying cause during the follow-up period. The limited sample size necessitated the presentation of cause-specific mortality for the three leading causes of death by broad categories: neoplasms (codes C00 to D48), diseases of the circulatory system (codes I00 to I99), diseases of the respiratory system (codes J00 to J99) (Appendix Table B). The neoplasms category includes neoplasms that are benign, as well as those that are of uncertain or unknown behaviour.

Covariates

Age in years was grouped (65 to 74, 75 to 84, 85 or older) for descriptive statistics and entered as a continuous variable in the multivariate analyses. Sex was classified as either male or female. Older adults refers to those aged 65 or older. Household education—the highest level obtained by any household member—was selected as a measure of socioeconomic status

(less than post-secondary, post-secondary graduation or more). Education was preferred over income, which can change substantially with retirement and other changes in workforce participation. A combination of marital status and living arrangements classified individuals as married or common-law versus not married or common-law (i.e., single, widowed or divorced). The latter group was further divided into those who were living alone versus those living with others, where others could be a child, friend, sibling or other person. Official language status was classified as French-speaking minority (French-speakers living outside Quebec), English-speaking minority (English-speakers living in Quebec) or non-minority speaker. People who did not speak either official language (less than 1% of the sample) were excluded from the prevalence estimates. Smoking status was categorized as current smoker, former smoker or never a smoker. Drinker was based on alcohol use in the 12 months prior to the CCHS interview and was

Table 2
Prevalence of frailty, by sex and other selected characteristics, household population aged 65 or older, Canada excluding the territories, 2013 to 2014

Characteristics	Both sexes				Male				Female			
	Number '000	%	95% confidence interval		Number '000	%	95% confidence interval		Number '000	%	95% confidence interval	
			from	to			from	to			from	to
Overall	1,130	21.8	21.0	22.6	434	18.3	17.2	19.4	696	24.7 [†]	23.6	25.8
Age group												
65 to 74 [‡]	467	15.0	14.2	15.9	191	13.0	11.7	14.3	276	16.8 [†]	15.7	18.0
75 to 84	428	26.9 [*]	25.3	28.5	169	23.4 [*]	21.1	25.8	259	29.8 ^{**}	27.7	32.0
85 or older	235	48.0 [*]	45.0	51.1	74	40.9 [*]	35.7	46.4	161	52.2 ^{**}	48.6	55.8
Education												
Post-secondary [†]	581	19.0	18.0	20.0	244	16.2	14.8	17.7	336	21.6 [†]	20.2	23.1
Less than post-secondary	496	25.9 [*]	24.7	27.2	171	22.3 [*]	20.4	24.3	325	28.3 ^{**}	26.6	30.1
Marital status and living arrangement												
Married or common-law [†]	606	18.2	17.2	19.2	324	17.4	16.1	18.8	281	19.3	17.8	20.8
Not married or common-law												
Living with others	163	36.0 [*]	32.2	40.0	27	24.6 [*]	18.6	31.8	136	39.7 ^{**}	35.0	44.6
Living alone	360	25.5 [*]	24.3	26.8	83	20.7 [*]	18.6	22.9	278	27.5 ^{**}	26.1	28.9
Province or territory												
Newfoundland and Labrador	20	22.8	19.4	26.6	8	19.3	15.0	24.4	12	26.0 [†]	21.3	31.3
Prince Edward Island	5	18.9	15.0	23.4	2 [£]	14.3 [£]	9.4	21.0	3	22.8 [†]	17.3	29.4
Nova Scotia	40	24.7 [*]	22.1	27.5	18	24.9 [*]	20.6	29.7	22	24.6	21.3	28.1
New Brunswick	34	26.6 [*]	23.6	29.7	14	23.4 [*]	19.2	28.2	20	29.3 [*]	25.3	33.5
Quebec	241	18.5 [*]	17.0	20.2	90	15.2 [*]	13.1	17.5	151	21.3 ^{**}	19.2	23.6
Ontario	465	23.3 [*]	21.8	24.8	173	19.1	17.1	21.4	292	26.7 ^{**}	24.6	28.8
Manitoba	41	23.7	21.1	26.5	13	16.8	13.4	21.0	28	29.3 ^{**}	25.1	33.8
Saskatchewan	34	23.1	20.6	25.8	15	21.6	18.0	25.8	20	24.4	21.2	27.8
Alberta	96	22.1	19.8	24.7	37	18.2	15.1	21.8	59	25.6 [†]	22.2	29.2
British Columbia	152	20.8	18.7	23.0	64	18.6	15.8	21.8	88	22.7 [†]	20.0	25.6
Yukon, Northwest Territories, Nunavut	2 [£]	26.4 [£]	18.7	35.8	1 [£]	25.5 [£]	14.9	40.2	1 [£]	27.4	19.9	36.5
Official language minority												
French-speaking minority	41	23.9	20.8	27.2	16	21.6	17.4	26.4	25	25.6	21.6	30.0
English-speaking minority	37 [£]	24.7	17.8	33.3	18 [£]	26.4 [£]	17.0	38.4	19 [£]	23.4 [£]	15.2	34.3
Non-minority speaker [†]	996	21.1	20.3	21.9	388	17.8	16.7	19.0	609	23.9 [†]	22.8	25.0

^{*} significantly different from estimate for reference category (p < 0.05)

[†] significantly different from men (p < 0.05)

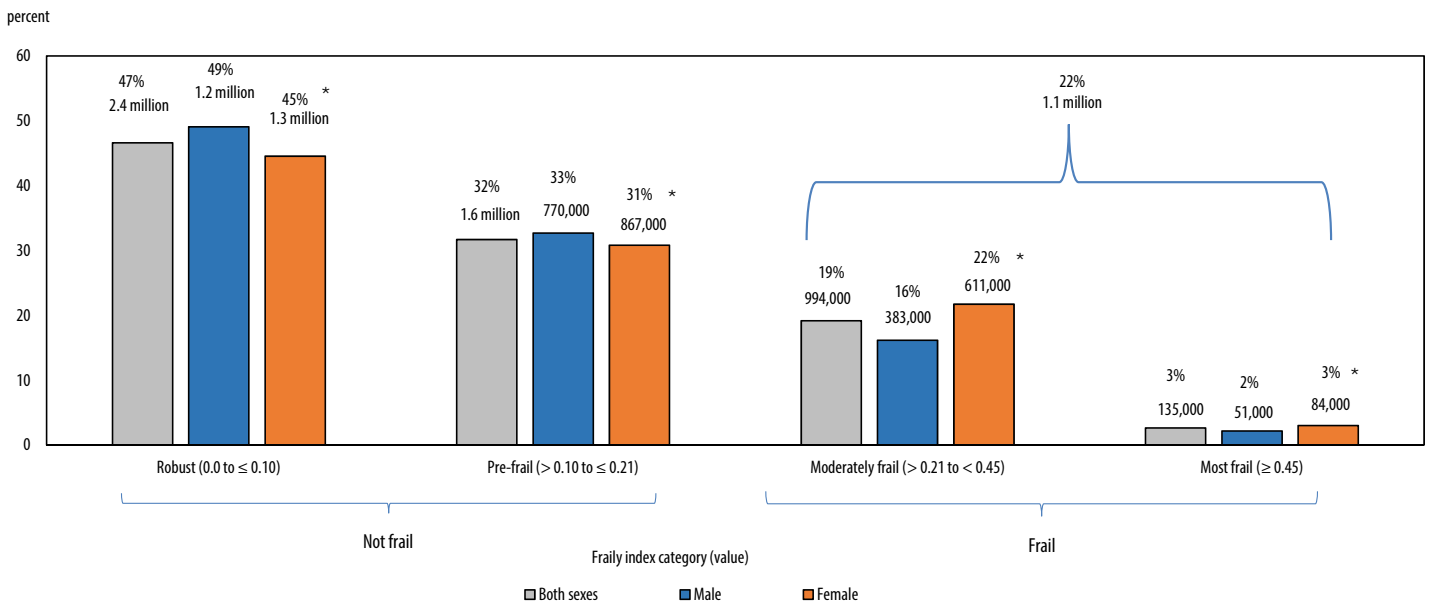
[‡] reference category

[£] use with caution

Notes: The reference category for the provinces and territories is the rest of Canada. Official language minority estimates exclude people who do not speak either official language.

Sources: Statistics Canada, Canadian Community Health Survey, 2013 and 2014, linked to the Canadian Vital Statistics - Death Database up to December 31, 2017.

Figure 1
Percentage distribution and estimated numbers, by frailty category, household population aged 65 or older, Canada, 2013 to 2014



* significantly different from men (p < 0.05)

Sources: Statistics Canada, Canadian Community Health Survey, 2013 and 2014, linked to the Canadian Vital Statistics - Death Database up to December 31, 2017.

Table 3
Number and percentage of all-cause deaths from 2013 and 2014 to 2017, by frailty, sex and age group, household population aged 65 or older, Canada excluding the territories, 2013 to 2014

Characteristics	Total				Frailty				Frailty					
	Total		Frail		Frail		Not frail		Total		Frail		Not frail	
	Number '000	%	Number '000	%	Number '000	%	Number '000	%	Number '000	%	Number '000	%	Number '000	%
Overall	575	11.1	287	25.4 *	288	7.1	10.5	11.7	23.7	27.3	6.6	7.7		
Sex														
Male	306	12.9	132	30.5 *	174	9.0	11.9	14.0	27.3	33.9	8.0	10.0		
Female	269	9.5	155	22.3 *	114	5.4	8.9	10.2	20.4	24.3	4.9	6.0		
Age group (years)														
65 to 74	164	5.3	63	13.4 *	101	3.8	4.8	5.8	11.6	15.6	3.4	4.3		
75 to 84	244	15.3	122	28.4 *	122	10.5	14.1	16.7	25.5	31.6	9.3	11.9		
85 or older	167	34.2	103	43.8 *	64	25.2	31.2	37.2	39.3	48.5	21.8	29.1		

* significantly different from estimate for not frail (p < 0.05)

Sources: Statistics Canada, Canadian Community Health Survey, 2013 and 2014, linked to the Canadian Vital Statistics - Death Database up to December 31, 2017.

classified as regular (once per month or more), occasional (less than monthly) or never.

Analytical techniques

The number and percentage of older adults were presented by frailty status (frail versus not frail) and by more specific categories (robust, pre-frail, moderately frail or most frail). Cross-tabulations were used to estimate the prevalence of frailty by sociodemographic characteristics: sex, age group, education, marital status and living arrangement, province or territory, and official language status. The number and percentage of deaths among the 2013 and 2014 cohort during the follow-up period were estimated for the frail and not frail categories. Associations between the more detailed (four) frailty categories

and mortality were examined using Cox proportional hazards models adjusted for age, sex, household education, marital status and living arrangements, smoking, and alcohol use. Preliminary models for all-cause and cause-specific mortality were stratified by sex (data not shown). The results were consistent with models for both sexes together. Therefore, the data were combined into single models that controlled for sex. Additionally, models were repeated using a scaled continuous FI so that hazard ratios were expressed per 0.1 higher frailty (equating to a 10% increase).

Sampling weights were used to account for unequal probabilities of selection and reduce the potential for bias resulting from differing response, share and agreement-to-link rates. Confidence intervals (95%) and significance testing were

estimated with the bootstrap technique (500 iterations). Comparisons were done using t-tests, and significance level alpha was set to 0.05. The data were analyzed using SAS-Callable SUDAAN 11.0 to account for any underestimation of standard errors resulting from the complex survey design.²⁷

Results

Baseline characteristics of the study population

The weighted study sample (n=29,302) represented an estimated population of 5.2 million people aged 65 or older living in private households. The mean age of the study population was 74 years in 2013 and 2014. Among the study population, almost half (46%) were men, most (64%) were married or common-law, and 62% lived in households where at least one person was a postsecondary graduate.

Prevalence of frailty

By applying the previously validated²³ cut-point of greater than 0.21, it was determined that an estimated 22% (1.1 million) of community-dwelling older adults were frail (Table 2; Figure 1). Frailty increased with age, ranging from 15% in the youngest age group (65 to 74) to almost half (48%) of the population aged 85 or older. Females in all age groups were more likely to be frail. Individuals from lower education households and those who were not married or in a common-law relationship were also more likely to be frail. The percentage of older adults who were frail was lower in Quebec than in the rest of Canada, and higher in Nova Scotia, New Brunswick, Ontario and Manitoba. No associations were evident between official language status and frailty.

The population of older adults who were frail (22%) included 19% classified as moderately frail and 3% who were most frail. The latter group scored 0.45 or higher on the FI (Figure 1). The

Table 4
Adjusted hazard ratios relating cause of death during a three-to-five-year follow-up period to frailty category, household population aged 65 or older, Canada excluding the territories, 2013 to 2014

Characteristics	Cause of death												
	All cause			Neoplasm			Disease of the circulatory system			Disease of the respiratory system			
	Adjusted hazard ratio	95% confidence interval		Adjusted hazard ratio	95% confidence interval		Adjusted hazard ratio	95% confidence interval		Adjusted hazard ratio	95% confidence interval		
	from	to	from	to	from	to	from	to	from	to	from	to	
Frailty category													
Robust (0.0 to ≤ 0.10) [†]	1.0	...	...	1.0	...	...	1.0	...	...	1.0	...	...	...
Pre-frail (> 0.10 to ≤ 0.21)	1.5 *	1.3	1.8	1.5 *	1.1	2.0	1.4 *	1.0	1.9	2.1 *	1.2	3.6	
Moderately frail (> 0.21 to < 0.45)	2.9 *	2.4	3.4	2.0 *	1.5	2.6	3.0 *	2.2	4.3	4.7 *	2.9	7.6	
Most frail (≥ 0.45)	5.9 *	4.5	7.7	1.8 *	1.0	3.1	5.4 *	3.0	9.8	7.6 *	3.6	16.4	
Sex													
Male	1.8 *	1.6	2.0	1.6 *	1.3	2.1	1.9 *	1.5	2.3	2.2 *	1.5	3.1	
Female [‡]	1.0	...	...	1.0	...	...	1.0	...	...	1.0	...	...
Age (continuous)	1.09 *	1.08	1.10	1.07 *	1.05	1.08	1.12 *	1.10	1.14	1.11 *	1.08	1.14	

... not applicable

* significantly different from estimate for reference category (p < 0.05)

† reference category

Notes: In addition to age and sex, the models controlled for alcohol use in the past 12 months (regular, occasional, never), smoking (current, former, never), household education, and marital status and living arrangements; data not shown.

Sources: Statistics Canada, Canadian Community Health Survey, 2013 and 2014, linked to the Canadian Vital Statistics - Death Database up to December 31, 2017.

Table 5
Number and percentage distribution of deaths from 2013 and 2014 to 2017, by frailty and underlying cause of death, household population aged 65 or older, Canada excluding the territories, 2013 to 2014

Characteristics	Total				Frailty							
	Total				Frail				Not frail			
	Number '000	%	95% confidence interval from	to	Number '000	%	95% confidence interval from	to	Number '000	%	95% confidence interval from	to
Total deaths	575	100.0	...	...	287	100.0	...	...	288	100.0	...	...
Underlying cause of death												
Neoplasm	205	35.6	32.8	38.4	72	25.0 *	21.9	28.5	133	46.1	41.9	50.2
Diseases of the circulatory system	165	28.8	26.3	31.4	92	31.9 *	28.3	35.7	74	25.6	22.3	29.2
Diseases of the respiratory system	59	10.2	8.7	12.0	35	12.2 *	9.8	14.9	24	8.3	6.4	10.7
Other causes	147	25.5	23.2	27.9	89	30.9 *	27.3	34.7	58	20.0	17.2	23.2

... not applicable

* significantly different from estimate for not frail (p < 0.05)

Note: Causes of death comprising "other causes" were too few to be reported individually.

Sources: Statistics Canada, Canadian Community Health Survey, 2013 and 2014, linked to the Canadian Vital Statistics - Death Database up to December 31, 2017.

majority of older adults (78%) were at or below the 0.21 cut-off for frailty—47% were classified as robust (FI at or below 0.10), while 32% were pre-frail (FI greater than 0.10 to the 0.21 cut-off).

Frailty and all-cause mortality

Over the follow-up period of three to five years, 11% (575,000) of the 2013 and 2014 cohort of older adults died—13% of males and 10% of females (Table 3). Older adults who were frail were more than three times as likely to die as those who were not frail (25% versus 7%). The increased likelihood of death among frail individuals was evident for males and females and across all age groups.

Table 4 presents the risk of mortality for older adults who were robust, pre-frail, moderately frail or most frail, controlling for covariates. Even those who were classified as pre-frail faced a greater risk of mortality than those in the robust group. Older adults who were categorized as pre-frail had a 50% higher risk of mortality, and the risk was even higher for individuals in the moderately frail or most frail groups.

Leading causes of mortality

The leading underlying causes of death among the 2013 and 2014 cohort were neoplasms, diseases of the circulatory system and diseases of the respiratory system (Table 5). A greater proportion of the deaths from causes associated with the circulatory and respiratory systems occurred among older adults who were frail compared with those who were not, while the opposite was observed for deaths caused by neoplasms. Models revealed that, compared with those who were robust, older adults who were pre-frail or worse had higher risks of mortality (hazard ratio [HR] between 1.4 and 7.6) from each of the leading causes, even after accounting for sex, age, smoking, alcohol use, education, and marital status and living arrangement (Table 4). Similarly, Cox survival models using a continuous FI demonstrated that a 10% higher baseline frailty (i.e., a 0.1 FI increment) was associated with a higher risk of all-cause mortality (HR = 1.5; 95% confidence interval [CI]: 1.4–1.6), as well as death from neoplasms (HR = 1.2; 95% CI: 1.1–1.3), circulatory disease (HR = 1.5; 95% CI: 1.3–1.6) and respiratory disease (HR = 1.6; 95% CI: 1.4–1.8) (data not shown in table).

Discussion

This study presented the prevalence of frailty among older community-dwelling Canadians in 2013 and 2014 using an index developed and validated with Canadian data. Mortality risk was estimated prospectively in relation to FI scores using linked population-based survey and vital statistics death data.

Employing the previously validated cut-point,²³ an estimated 22% (1.1 million) of older adults were frail. This is consistent with the pooled prevalence of 24% frailty in the population aged 65 and older based on previous studies using an accumulation

of deficits approach,¹⁸ including an earlier Canadian study that estimated that 23% of older adults were frail in 1994 and 1995.²⁸ Additionally, another Canadian study based on data collected between 2007 and 2013 estimated that 20% of older adults were frail.²⁹ These results support the notion that FI scoring is robust despite differences in methodology and the number of deficits included,¹⁶ and also suggest that the prevalence of frailty in the community-dwelling Canadian population may be stable (at least when using a deficit accumulation approach, which tends to yield higher estimates of frailty than the phenotype approach).^{18,28}

Researchers have identified a male–female health-survival paradox such that, although females are more likely than males to experience ill health, they also tend to have greater longevity.^{12,30} Evidence from this and from previous studies^{30,31} demonstrates that sex differences in the FI are characteristic of the paradox, i.e., females have a higher prevalence of frailty, but males who are frail have a greater risk of mortality than females who are frail, independent of age. As long as females have a longer average life expectancy³² and a higher likelihood of being frail,^{18,28} older females who are frail will outnumber males in the same condition and their greater need for residential care will likely continue.³³

In this study, older adults were further classified into four groups, from robust to most frail. In addition to the 22% of older adults who were frail, 32% (1.6 million) were in the pre-frail category. Although these individuals did not meet the criterion for frailty, they were nevertheless at a greater risk of mortality than the robust group. Consistent with previous studies, it was found that both frailty and pre-frailty were associated with an increased risk of all-cause mortality, over and above the impact of age.^{10,18,34} The pre-frail group presents a potential early intervention point to manage a decline in older adults who are on a frailty trajectory but have not yet been classified as frail.^{9,35} Promoting increased physical activity and decreased sedentary time, as well as addressing loneliness and social isolation, could help prevent frailty or slow the decline among those who are already frail,^{9,36–40} thereby contributing to opportunities for aging in place and reducing the risk of mortality.

Fewer studies have examined frailty with respect to cause-specific mortality^{20,21,31,41,42} and results have been mixed. This study showed that the association between increasing frailty and a higher risk of mortality persisted in fully adjusted models for the three major underlying causes of death examined: neoplasms, circulatory diseases and respiratory diseases. Both frail and pre-frail older adults had 1.6 to 2.0 times the risk of mortality from neoplasms than did robust seniors. Some previous studies did not find frailty to be significantly associated with an increased risk of cancer mortality^{20,31} or incident cancer,⁴³ while others found that frailty—but not pre-frailty—increased the risk of cancer mortality.^{21,41} In this study, as well as a previous study²¹ that employed a phenotype model of frailty, the proportion of deaths from cancer was lower among those who were frail than among those who were not frail, as measured at baseline. It is possible that frailty adds to

the risk presented by other conditions, resulting in greater variability in causes of death among frail populations than among non-frail populations.²¹

Diseases of the circulatory system were also associated with an increased risk of mortality for both frail and pre-frail seniors in this study. Some studies have demonstrated that frailty is associated with an increased risk of cardiovascular disease-related mortality,^{20,21,41,42} while one study found this to be the case for females but not males.³¹ Although it is difficult to make direct comparisons because of differences in measures of frailty, the use of categorical or continuous variables, and variation in cause of death definitions, the findings of previous studies generally support an increased risk of mortality from circulatory disease among older adults who were frail compared with those who were robust.

Death from respiratory disease causes was studied less than other causes. Being pre-frail or frail was associated with a two- to eight-fold increased risk of respiratory disease mortality in this study, which is consistent with previous findings.^{20,21}

Strengths and limitations

A strength of this study is the large sample, which is representative of the community-dwelling population of older adults from 2013 to 2014. It includes linkages to quality vital statistics death data providing a follow-up period of three to five years. The self-reported data for the FI and covariates present a potential weakness, as they could not be verified by any other source, although body mass index was adjusted to take into account known patterns of misreporting.²⁵

FIs are typically constructed with dichotomous variables and scored using the number of deficits as a proportion of total deficits. A strength of the FI in this study is that it includes variables that encompass degrees of a deficit contributing to a more nuanced overall score. The scores at either extreme of an individual variable more accurately capture those with the lowest and highest degrees of deficit, for example, “walks without difficulty and without aids” (score: 0.0) and “cannot walk” (1.0).

Frailty was measured at baseline in the cross-sectional CCHS. The duration of frailty status prior to the CCHS interview was not known. Subsequent changes in frailty over the follow-up period could not be measured. Wang⁴⁴ found that any history of frailty, including a desired (positive) transition from frail to robust, was associated with a higher risk of mortality compared with those who never experienced frailty. Consequently, estimated associations between baseline frailty and mortality may underestimate true associations.

It is not known whether other behaviours or characteristics measured at baseline changed over the follow-up period. For example, alcohol consumption in the past 12 months reported at the CCHS interview may have changed during the follow-up period. Behaviours may have changed because of illness or other circumstances and may not necessarily reflect usual lifetime or long-term behaviour.

The CCHS does not include residents of long-term care facilities, which excludes those most likely to be frail from prevalence estimates of frailty. Probabilistic linkage was used to match survey records to death information, and the possibility of false or missed links exists. The CVSD includes death information for events occurring in Canada predominantly. Respondents who died outside of Canada account for less than 0.2% of the linked data.

Conclusion

An estimated 22% of older Canadian adults were classified as frail, and an additional 32% were classified as pre-frail. Both categories were associated with an increased risk of all-cause mortality among community-dwelling older adults over a three- to five-year follow-up period. This was also the case for mortality from neoplasms, circulatory disease and respiratory disease. Information on cause-specific mortality risk associated with frailty can help inform treatment and policy approaches for preventing frailty-related mortality. Future research using longitudinal data could establish whether older adults who are classified as pre-frail are at risk of becoming frail. If this is the case, the pre-frail category represents a potential intervention point for preventing or reducing the progression to frailty in this group.

Appendix Table A

Deficits included in the Canadian Community Health Survey-based frailty index

Item number, concept/variable	Description	Frailty index value
1. GENDHDI: Self-perceived health	Excellent/very good	0.00
	Good	0.50
	Fair/poor	1.00
2. GEN_02: Change in health (past year)	Much better/somewhat better/about the same	0.00
	Somewhat worse	0.50
	Much worse	1.00
3. HWTDISW: Body mass index (adjusted (Gorber 2008))	Normal/overweight	0.00
	Obese	0.50
	Underweight	1.00
4. RACDPAL: Participation and activity limitation	Never	0.00
	Sometimes	0.50
	Often	1.00
5. HUIDSPE: Speech	Understood by everyone or only those who know them	0.00
	Partially understood by everyone	0.50
	Not understood by anyone or partially understood by those who know them	1.00
6. HUIDEMO: Emotional health	Happy and interested in life	0.00
	Somewhat happy	0.25
	Somewhat unhappy	0.50
	Very unhappy	0.75
	So unhappy that life is not worthwhile	1.00
7. HUPDPAD: Pain	None	0.00
	Pain does not prevent activity	0.25
	Pain prevents a few activities	0.50
	Pain prevents some activities	0.75
	Pain prevents most activities	1.00
8. HUIDVIS: Vision	Sees with or without glasses	0.00
	Reads newsprint with or without glasses, cannot see person across the street with glasses	0.25
	Sees person across the street with or without glasses, cannot read newsprint without glasses	0.50
	Cannot read newsprint or see person across the street with glasses	0.75
	Cannot see	1.00
9. HUIDHER: Hearing	Hears in group without hearing aid (HA)	0.00
	Hears one-on-one without HA, needs HA for group	0.20
	Can hear with HA	0.40
	Hears one-on-one without HA, cannot hear with HA in group	0.60
	Hears one-on-one with HA, cannot hear with HA in group	0.80
	Cannot hear	1.00
10. HUIDMOB: Mobility	Walks without difficulty and without aids	0.00
	Walks outside with difficulty, no help or aids needed	0.20
	Walks outside with aids, no help of another person	0.40
	Walks short distances unaided, needs wheelchair for longer distances	0.60
	Walks short distances with help, needs wheelchair for longer distances	0.80
	Cannot walk	1.00
11. HUIDCOG: Cognition	Can remember most things, think clearly, solve problems	0.00
	Somewhat forgetful, but thinks, solves problems	0.20
	Remembers most things; some difficulty to think, solve problems	0.40
	Somewhat forgetful; some difficulty to think, solve problems	0.60
	Very forgetful; great difficulty to think, solve problems	0.80
	Unable to remember anything, think, solve problems	1.00
12. HUIDDEX: Dexterity	Full use of two hands and 10 fingers	0.00
	Limited use of hands, no help needed	0.20
	Limited use of hands, uses special tools	0.40
	Limited use of hands, needs help for some tasks	0.60
	Limited use of hands, needs help for most tasks	0.80
	Limited use of hands, needs help for all tasks	1.00
13 to 23. CCC_xxx: Chronic conditions	Absence of condition	0.00
	Presence of condition: Arthritis or rheumatism; back problems other than arthritis; high blood pressure; chronic bronchitis, emphysema or COPD; heart disease; diabetes; cancer; effects of stroke; urinary incontinence; Alzheimer's disease or dementia	1.00
24 to 28. ADL_xx: Activities of daily living	Able to perform activity	0.00
	Limited in activity: Preparing meals, getting to appointments and running errands, doing everyday housework, doing personal care such as washing and dressing, moving inside the house, looking after personal finances	1.00
29. INU_10: Fall-related injury	No fall-related injuries (past 12 months)	0.00
	Fall-related injury (past 12 months)	1.00
30. PAC_1A: Walked for exercise	Walked for exercise (past three months)	0.00
	No walking for exercise (past three months)	1.00

Note: COPD = Chronic obstructive pulmonary disease.

Source: Statistics Canada, Canadian Community Health Survey, 2013 and 2014.

Appendix Table B
ICD-10 Cause of death codes

Codes	Description
Neoplasms (C00-D48)	
C00 to C97	Malignant neoplasms
C00 to C75	Malignant neoplasms, stated or presumed to be primary, of specified sites, except of lymphoid, haematopoietic and related tissue
C00 to C14	Lip, oral cavity and pharynx
C15 to C26	Digestive organs
C30 to C39	Respiratory and intrathoracic organs
C40 to C41	Bone and articular cartilage
C43 to C44	Skin
C45 to C49	Mesothelial and soft tissue
C50	Breast
C51 to C58	Female genital organs
C60 to C63	Male genital organs
C64 to C68	Urinary tract
C69 to C72	Eye, brain and other parts of central nervous system
C73 to C75	Thyroid and other endocrine glands
C76 to C80	Malignant neoplasms of ill-defined, secondary and unspecified sites
C81 to C96	Malignant neoplasms, stated or presumed to be primary, of lymphoid, haematopoietic and related tissue
C97	Malignant neoplasms of independent (primary) multiple sites
D00 to D09	In situ neoplasms
D10 to D36	Benign neoplasms
D37 to D48	Neoplasms of uncertain or unknown behaviour
Diseases of the circulatory system (I00-I99)	
I00 to I02	Acute rheumatic fever
I05 to I09	Chronic rheumatic heart diseases
I10 to I15	Hypertensive diseases
I20 to I25	Ischemic heart diseases
I26 to I28	Pulmonary heart disease and diseases of pulmonary circulation
I30 to I52	Other forms of heart disease
I60 to I69	Cerebrovascular diseases
I70 to I79	Diseases of arteries, arterioles and capillaries
I80 to I89	Diseases of veins, lymphatic vessels and lymph nodes, not elsewhere classified
I95 to I99	Other and unspecified disorders of the circulatory system
Diseases of the respiratory system (J00-J99)	
J00 to J06	Acute upper respiratory infections
J09 to J18	Influenza and pneumonia
J20 to J22	Other acute lower respiratory infections
J30 to J39	Other diseases of upper respiratory tract
J40 to J47	Chronic lower respiratory diseases
J60 to J70	Lung diseases due to external agents
J80 to J84	Other respiratory diseases principally affecting the interstitium
J85 to J86	Suppurative and necrotic conditions of the lower respiratory tract
J90 to J94	Other diseases of the pleura
J95 to J99	Other diseases of the respiratory system

Note: ICD-10 stands for the International Classification of Diseases, 10th edition.

Source: ICD-10 Version 2019, available at <https://icd.who.int/browse10/2019/en>.

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