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RESEARCH PAPER

The association between frailty, long-term care home characteristics and COVID-19 mortality before and after SARS-CoV-2 vaccination: a retrospective cohort study

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Abstract

Background: The relative contributions of long-term care (LTC) resident frailty and home-level characteristics on COVID-19 mortality has not been well studied. We examined the association between resident frailty and home-level characteristics with 30-day COVID-19 mortality before and after the availability of SARS-CoV-2 vaccination in LTC.
Methods: We conducted a population-based retrospective cohort study of LTC residents with confirmed SARS-CoV-2 infection in Ontario, Canada. We used multi-level multivariable logistic regression to examine associations between 30-day COVID-19 mortality, the Hubbard Frailty Index (FI), and resident and home-level characteristics. We compared explanatory models before and after vaccine availability.
Results: There were 11,179 and 3,655 COVID-19 cases in the pre- and post-vaccine period, respectively. The 30-day COVID-19 mortality was 25.9 and 20.0% during the same periods. The median odds ratios for 30-day COVID-19 mortality between LTC homes were 1.50 (95% credible interval [CrI]: 1.41–1.65) and 1.62 (95% CrI: 1.46–1.96), respectively. In the pre-vaccine period, 30-day COVID-19 mortality was higher for males and those of greater age. For every 0.1 increase in the Hubbard FI, the odds of death were 1.49 (95% CI: 1.42–1.56) times higher. The association between frailty and mortality remained consistent in the post-vaccine period, but sex and age were partly attenuated. Despite the substantial home-level variation, no home-level characteristic examined was significantly associated with 30-day COVID-19 mortality during either period.
Interpretation: Frailty is consistently associated with COVID-19 mortality before and after the availability of SARS-CoV-2 vaccination. Home-level characteristics previously attributed to COVID-19 outcomes do not explain significant home-to-home variation in COVID-19 mortality.

Keywords: COVID-19, long-term care homes, frailty, multi-level models, older adults, older people

Key Points

- Multi-level modelling suggests that the long-term care home setting is strongly associated with COVID-19 mortality amongst residents.
- Home-level factors examined were not associated with COVID-19 mortality suggesting that more is going on at the home level.
- Frailty as a strong predictor of mortality pre- and post-vaccine suggests that it is a robust predictor of risk of improved survival.
- Consistent with vaccine effectiveness studies, there was a lower risk of COVID-19 mortality post-vaccine compared to pre-vaccine in Ontario, Canada.

Introduction

Frail older adults in long-term care (LTC) have a higher risk of COVID-19 mortality compared to those who are not frail or pre-frail [1–4]. Frailty is a graded health state and a geriatric syndrome defined as a decreased physiologic reserve and increased vulnerability to stressors and adverse health outcomes [5]. Frail individuals are more likely to experience health instability and permanent health decline post-COVID-19 illness [1–4]. Many frailty measures exist and are utilised depending on the care setting and available data sources [5, 6].

In Ontario, Canada's most populous province, 626 licensed LTC homes deliver 24-h care to residents who cannot live independently. These residents receiving care in LTC homes were disproportionately affected by COVID-19, as more than two-thirds of COVID-19 deaths occurred in LTC residents during Ontario's first two waves of the pandemic [7, 8]. Vaccine distribution in Ontario was prioritised for LTC residents who are vulnerable to SARS-CoV-2 infection and distribution began on 23 December 2020 [9]. Frailty may affect immune responses to COVID-19 vaccinations, given that frail older adults generally have less robust immunological responses to vaccinations, and immune protection diminishes more quickly amongst LTC residents than the general population [10–12]. It is unclear if the influence of frailty on COVID-19 mortality was substantially modified by vaccination, recognising that vaccination has led to less morbidity and mortality [9, 13].

Previous studies have shown that COVID-19 mortality varies between homes and its spread is affected by home-level characteristics [5, 14–16]. These include LTC ownership type (i.e. public versus private), chain ownership, nursing home crowding, staffing and home size (i.e. larger homes have more opportunity for spread and transmission) [14–16]. However, it is rare for these studies to account for resident health status, such as frailty, and to control for clustering within residents of the same LTC homes.

The goal of our study was to simultaneously evaluate the associations between 30-day COVID-19 mortality and frailty, whilst considering resident and home-level characteristics in Ontario, Canada. We used a multi-level design with residents nested within LTC homes. We hypothesised that residents with higher levels of frailty would have a higher risk of death and that after SARS-CoV-2 vaccination availability, the relative odds of death would be lower between more frail and less frail residents.

Methods

Our study was approved by the Hamilton Integrated Research Ethics Board (HiREB #10959-C). We used the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement in reporting this study [17].

Study design, setting and population

We conducted a population-based retrospective cohort study of LTC residents in Ontario, Canada by linking multiple health administrative datasets. LTC residents are admitted and provided a bed based on need, prioritisation and availability of beds [18]. Our cohort comprised LTC residents positive for SARS-CoV-2 through a polymerase chain reaction test. If multiple positive test results were present for a given case, the first incident was utilised as the first day of infection to reduce bias. Ontario LTC homes are regulated, inspected and publicly funded by the provincial government and are operated on either a not-for-profit or for-profit basis. LTC is an extended healthcare service, and as a result, it is not fully covered by public funds and requires residents to pay a partial fee out-of-pocket or through supplemental insurance.

Data sources

We obtained de-identified data from the Ontario Ministry of Health for COVID-19 research on priority populations. The data sources used included the Continuing Care Reporting System, which provided LTC admission and discharge dates. The Resident Assessment Instrument-Minimum Data Set (RAI-MDS) 2.0 provided resident characteristics. The RAI-MDS 2.0 is a standardised and comprehensive clinical assessment instrument mandated for all residents living in Ontario's 626 LTC homes. The instrument examines more than 300 items from 15 health domains, and the assessments are conducted on admission to LTC and quarterly by trained personnel [19]. Laboratory information and COVID-19

testing results were extracted from the Ontario Laboratories Information System and the Ontario Integrated Public Health Information System.

Study periods and outcome measure

The study period was from 26 February 2020 to 31 August 2021. We identified a start date of 26 February 2020 for Wave 1 according to Public Health Ontario [20]. The SARS-CoV-2 vaccine administration in Ontario LTC homes began on 23 December 2020, and 95% of all eligible residents received a first dose [9, 21]. As such, we classified two time-specific study periods, a pre-vaccine period (26 February 2020 to 31 December 2020) and a post-vaccine period (1 January 2021 to 31 August 2021) based on when vaccines were available and administered. The Omicron variant became the dominant circulating variant after our study period (November 2021) and was not included for analysis. Our primary outcome was 30-day mortality for residents classified with laboratory-verified SARS-CoV-2 infection (i.e. case fatality rate), consistent with the definition used in other studies [1, 2, 22]. We followed all residents until 30 September 2021, given the availability of our datasets.

Covariates

We calculated the Hubbard Frailty Index using 75 items validated in the RAI-MDS 2.0 instrument (see Supplementary Tables S1 and S2 for assessment items used). This frailty index (FI) was originally a 56-item deficient accumulation measure developed for an acute care patient population [23]. Frailty indices are continuous measures that allow for more granularity in their measure [24], which may improve statistical power and precision of estimates when compared to classifications of frailty [25].

We included resident and home-level characteristics based on prior work demonstrating their association with COVID-19 mortality [1, 2, 10, 11, 14–16, 22, 26]. We identified resident characteristics from the most recent MDS 2.0 assessment, including age groups (65–69, 70–74, 75–79, 80–84, 85–89, 90–94, 95+ years), sex, disease diagnoses and clinical scales related to activities of daily living, health instability, cognition and mood, and history of prior SARS-CoV-2 infection. We identified the following home characteristics: size (small: <96 beds, medium: 97–160 beds, large: 160+ beds), region of Ontario (Central, East, North, Toronto, West), type of ownership (municipal, non-profit, for-profit) and their respective crowding index (low: <2.0, high: 2.0–4.0). The crowding index was calculated based on work by Brown et al. and was based on the number of residents per bedroom and bathroom [16].

Statistical analysis

We calculated resident and home-level descriptive statistics for each period through means (continuous variables) and frequencies (categorical variables). Multi-level multivariable logistic regression models were used to estimate the association between resident and home-level characteristics and 30-day COVID-19 mortality. We examined changes per 0.1 increase in the FI. Effects were reported as odds ratios (OR) and 95% confidence intervals (CI). We adjusted for clustering by including random intercepts at the LTC home level. In each period, we fit three models: (i) a null model with no covariates, (ii) an adjusted model with resident and home-level characteristics and (iii) a final adjusted model with the FI, resident and home-level characteristics. We extracted measures of within-home variability from each model: the intraclass correlation (ICC), home-level variance and median odds ratio (MOR) with 95% credible intervals (CrI). We provide the MOR as it has a more straightforward interpretation of home-level variability than the ICC for logistic regression [27]. The MOR represents the average difference in risk between homes on the OR scale. To visualise how the effect of frailty changed between the pandemic periods on an absolute scale, we plotted marginal effects at the mean within each decile of the FI separately for each study period. All analyses were performed using SAS version 9.4 (SAS Institute).

Sensitivity analysis

For sensitivity analyses, we included history of SARS-CoV-2 infection as a covariate in post-vaccine period models. We also examined the robustness of frailty-related findings by testing associations with the Armstrong FI and the FRAIL-NH Scale. The Armstrong FI was calculated from 43 items in RAI-MDS 2.0, based on the original 50-item measure developed for a home care client population [28]. The FRAIL-NH scale, although not an index, is a simple scale designed specifically to identify frailty in LTC residents. The FRAIL-NH scale was modelled from the original measure for LTC residents with 11 items from the RAI-MDS 2.0 [29, 30]. The total score ranges from 0 to 14, with a suggested cut-off value of 6 for frailty [31]. We also tested an interaction term between the study period and frailty.

Results

Cohort

Across both study periods, 411 LTC homes were represented, comprising 14,834 residents with a positive SARS-CoV-2 infection between 26 February 2020 and 31 August 2021. Most residents (36.4%) had a FI between 0.5 and 0.6, indicating severe frailty. Supplementary Figure S1 shows the distribution of the Hubbard FI across all study periods for the entire cohort.

In the pre-vaccine period, there were 11,179 positive cases in 339 homes, with 7,363 women (65.9%) and 11,132 residents (99.6%) who did not have a prior positive SARS-CoV-2 infection (Table 1). Consistent with population-level

Table 1. Characteristics of SARS-CoV-2-positive residents, by study period.

Characteristic	**Pre-vaccine period** (26 February 2020 to 31 December 2020) $n = 11,179$	**Post-vaccine period** (1 January 2021 to 31 August 2021) $n = 3,655$
Age group, No. (%)		
<65 years	823 (7.4)	227 (6.2)
65–69 years	583 (5.2)	191 (5.2)
70–74 years	869 (7.8)	289 (7.9)
75–79 years	1,251 (11.2)	419 (11.5)
80–84 years	1,844 (16.5)	566 (15.5)
85–89 years	2,405 (21.5)	825 (22.6)
90–94 years	2,263 (20.2)	739 (20.2)
95+ years	1,141 (10.2)	399 (10.9)
Female sex, No. (%)	7,363 (65.9)	2,466 (67.5)
Frailty		
Armstrong, mean (SD)	0.33 (0.07)	0.33 (0.07)
Armstrong, median (IQR)	0.33 (0.28–0.37)	0.33 (0.28–0.37)
Hubbard, mean (SD)	0.49 (0.11)	0.50 (0.12)
Hubbard, median (IQR)	0.50 (0.43–0.57)	0.51 (0.43–0.57)
FRAIL-NH, mean (SD)	8.82 (2.01)	8.91 (2.03)
FRAIL-NH, median (IQR)	9.0 (8.0–10.0)	9.00 (8.0–10.0)
Prior SARS-CoV-2 infection, No. (%)		
No prior positive	11,132 (99.6)	3,461 (94.7)
31–90 days ago	6 (0.05)	64 (1.8)
91–180 days ago	26 (0.23)	70 (1.9)
181+ days	15 (0.13)	60 (1.6)
Falls (last 30 days), **No. (%)**	1,610 (14.4)	581 (15.9)
Medications, No. (%)		
0–4 medications	868 (7.8)	239 (6.5)
5–9 medications	4,301 (38.5)	1,316 (36.0)
10–14 medications	4,154 (37.2)	1,357 (37.1)
15+ medications	1,856 (16.6)	743 (20.3)
Health service use, No. (%)		
Hospitalizations (last 90 days)	499 (4.5)	199 (5.4)
ER visits (last 90 days)	208 (1.9)	71 (1.9)
Physician visits (last 14 days)		
0 Physician visits	2,610 (23.3)	962 (26.3)
1–2 Physician visits	7,936 (71.0)	2,489 (68.1)
3+ Physician visits	633 (5.7)	204 (5.6)
Disease diagnoses, No. (%)		
Alzheimer's or dementia	7,063 (63.2)	2,275 (62.3)
Cancer	886 (7.9)	332 (9.1)
COPD/emphysema or asthma	1,789 (16.0)	681 (18.6)
Congestive heart failure	1,164 (10.4)	483 (13.2)
Depression	3,548 (31.7)	1,220 (33.4)
Diabetes	3,390 (30.3)	1,098 (30.0)
Renal failure	1,085 (9.7)	424 (11.6)
Stroke	2,295 (20.5)	734 (20.1)
Scales, mean (SD) [a]		
Activities of Daily Living (ADL)	3.91 (1.28)	3.93 (1.31)
Health Instability (CHESS)	0.71 (0.86)	0.86 (0.91)
Cognitive Performance Scale (CPS)	3.13 (1.57)	2.97 (1.63)
Depression Rating Scale (DRS)	1.39 (1.95)	1.60 (2.11)
30-day COVID-19 mortality, No. (%)	2,895 (25.9%)	732 (20.0%)

COPD, chronic obstructive pulmonary disease CHESS, Changes in Health, End-Stage Disease and Signs and Symptoms, which detects health instability and a person at risk of decline, scale from 0 to 5 CPS, Cognitive Performance Scale, which measures the degree of cognitive impairment, scale from 0 to 6 DRS, Depression Rating Scale, which measures the degree of depression, scale from 0 to 14 [a]ADL, Activities of Daily Living Hierarchy Scale, which includes personal hygiene, locomotion, eating and toileting, scale from 0 to 6

distributions, homes in the pre-vaccine period with COVID-19 cases were mostly private, for-profit (59.6%) and medium-sized, with 97–160 beds (41.9%) (Table 2). In this period, 2,895 residents (25.9%) died within 30 days (Table 1).

In the post-vaccine period, there were 3,655 positive cases in 300 homes, with 2,466 women (67.5%) and 3,461 residents (94.7%) who did not have a prior positive SARS-CoV-2 infection (Table 1). Again, consistent with population-level distributions, the homes in the post-vaccine

Table 2. Home characteristics for SARS-CoV-2-positive residents, by study period.

Characteristic	**Pre-vaccine period** (26 February 2020 to 31 December 2020) $n = 339$	**Post-vaccine period** (1 January 2021 to 31 August 2021) $n = 300$
Home size, No. (%)		
Small: <97 beds	81 (23.9)	60 (20.0)
Medium: 97–160 beds	142 (41.9)	132 (44.0)
Large: 160+ beds	116 (34.2)	108 (36.0)
Proportion of homes in rural area, No. (%)	29 (8.6)	30 (10.0)
Home region, No. (%)		
Central	96 (28.3)	84 (28.0)
East	83 (24.5)	72 (24.0)
North	15 (4.4)	11 (3.7)
Toronto	34 (10.0)	24 (8.0)
West	111 (32.7)	109 (36.3)
Chain ownership, No. (%)		
1 home, not in a chain	93 (27.4)	77 (25.7)
2–9 homes	88 (26.0)	79 (26.3)
10–19 homes	69 (20.4)	66 (22.0)
20+ homes	89 (26.3)	78 (26.0)
Home ownership type, No. (%)		
Municipal	86 (25.4)	71 (23.7)
Private non-profit	51 (15.0)	47 (15.7)
Private for-profit	202 (59.6)	182 (60.7)
Crowding index, No. (%)		
Low < 2.0	188 (55.5)	168 (56.0)
High 2.0–4.0	151 (44.5)	132 (44.0)

period with COVID-19 cases were mostly private, for-profit (60.7%) and medium-sized, with 97–160 beds (44.0%) (Table 2). In this group, 732 residents (20.0%) died within 30 days (Table 1).

Associations between covariates and COVID-19 mortality

Tables 3 and 4 summarise each period's multi-level multivariable logistic regression results.

In the pre-vaccine period, the null multi-level logistic regression model had significant home-level variability with a MOR of 1.45 (95% CrI: 1.36–1.57). In the final model (model 3), home-level variability was slightly increased with a MOR of 1.50 (95% CrI: 1.41–1.65). However, we did not find significant associations between measured home-level characteristics and 30-day COVID-19 death. Frailty and other resident-level characteristics were significant predictors. For every 0.1 increase in the Hubbard FI, the odds of death were 1.49 (95% CI: 1.42–1.56) times higher. We found strong associations for sex (male; OR: 2.15; 95% CI: 1.95–2.37) and increasingly stronger associations as age increased from 65 to 69 years (OR: 1.55; 95% CI: 1.11–2.17) to 95 years and older (OR: 6.70; 95% CI: 5.09–8.82).

In the post-vaccine period, the null multi-level logistic regression model had significant home-level variability with a MOR of 1.66 (95% CrI: 1.50–1.99). In the final model (model 3), there was a slight reduction but still significant home-level variability with a MOR of 1.62 (95% CrI: 1.46–1.96). Similar to the pre-vaccine period, we did not find any significant associations between measured home-level characteristics and the risk of death, but frailty and other resident-level characteristics were still significant predictors. The effect of frailty was similar to the pre-vaccine period; a 0.1 change in the Hubbard FI was associated with a 1.45 (95% CI: 1.33–1.59) times higher odds of death. Compared to the pre-vaccine period, sex was a weaker predictor (male; OR: 1.78; 95% CI: 1.48–2.15) and the effect of age within a given group was also weaker. There was no association for those who were 65 to 69 years (OR: 0.80; 95% CI: 0.41–1.56) and 70 to 74 years (OR: 1.11; 95% CI: 0.63–1.97) old, and increasingly stronger associations as age group increased from 75 to 79 years (OR: 1.75; 95% CI: 1.05–2.93) to 95 years and older (OR: 3.19; 95% CI: 1.91–5.31). Figure 1 shows that the risk of death increased with increasing frailty in both study periods but was generally lower in the post-vaccine period compared to the pre-vaccine for a given decile of the FI.

Sensitivity analysis

We observed similar results in associations when including a history of SARS-CoV-2 infection as a covariate in the post-vaccine period (Supplementary Table S3). Home-level variability decreased slightly but was still significant, with a MOR of 1.61 (95% CrI: 1.45–1.93). In our second sensitivity analysis examining the Armstrong FI and the FRAIL-NH scale, we observed similar trends, with no associations for home-level characteristics and strong associations for resident-level characteristics (Supplementary Table S4). The interaction term between frailty and the study period was not significant.

Table 3. Multi-level logistic regression models with resident and home-level covariates for the odds ratio of death within 30 days, pre-vaccine period (26 February 2020 to 31 December 2020), $n = 11{,}179$.

OR (95% CI)	Model 1: null	Model 2: resident and home characteristics	Model 3: Hubbard Frailty Index, residents and home characteristics
RESIDENT CHARACTERISTICS			
Male sex	–	2.02 (1.84; 2.23)	2.15 (1.95; 2.37)
Age group, years			
<65	–	*Reference*	*Reference*
65–69	–	1.57 (1.13; 2.19)	1.55 (1.11; 2.17)
70–74	–	2.30 (1.72; 3.08)	2.10 (1.57; 2.83)
75–79	–	2.83 (2.16; 3.72)	2.53 (1.92; 3.33)
80–84	–	3.76 (2.90; 4.88)	3.26 (2.50; 4.23)
85–89	–	4.39 (3.41; 5.67)	3.87 (3.00; 5.01)
90–94	–	6.16 (4.77; 7.95)	5.39 (4.16; 7.00)
95+	–	7.63 (5.81; 10.01)	6.70 (5.09; 8.82)
Hubbard Frailty Index (Δ 0.1)	–	–	1.49 (1.42; 1.56)
HOME CHARACTERISTICS			
Home size			
Small: <97 beds	–	*Reference*	*Reference*
Medium: 97–160 beds	–	1.02 (0.80; 1.29)	1.083 (0.84; 1.40)
Large: 160+ beds	–	1.05 (0.82; 1.33)	1.133 (0.88; 1.46)
Rural homes	–	1.02 (0.67; 1.56)	1.087 (0.69; 1.71)
Home region			
Central	–	*Reference*	*Reference*
East	–	1.19 (0.97; 1.45)	1.18 (0.96; 1.47)
North	–	0.48 (0.21; 1.1.)	0.57 (0.24; 1.35)
Toronto	–	0.97 (0.76; 1.23)	1.05 (0.81; 1.36)
West	–	1.10 (0.90; 1.34)	1.05 (0.84; 1.30)
Chain ownership			
1 home, not in a chain	–	*Reference*	*Reference*
2–9 homes	–	1.23 (0.98; 1.54)	1.24 (0.97; 1.59)
10–19 homes	–	1.11 (0.85; 1.44)	1.03 (0.78; 1.37)
20+ homes	–	1.06 (0.81; 1.38)	1.10 (0.83; 1.46)
Home ownership type			
Municipal	–	*Reference*	*Reference*
Private non-profit	–	1.04 (0.80; 1.35)	1.08 (0.82; 1.44)
Private for-profit	–	1.01 (0.79; 1.29)	1.13 (0.86; 1.47)
Crowding index			
Low < 2.0	–	*Reference*	*Reference*
High 2.0–4.0	–	1.10 (0.93; 1.29)	1.13 (0.95; 1.36)
HOME VARIABILITY STATISTICS			
Covariance estimate (95% CI)	0.15 (0.11; 0.23)	0.14 (0.10; 0.23)	0.18 (0.13; 0.28)
SE	0.029	0.029	0.035
ICC	0.044	0.042	0.053
MOR (95% CrI)	1.45 (1.36; 1.57)	1.44 (1.35; 1.57)	1.50 (1.41; 1.65)
AUC/C statistic (95% CI)	0.63 (0.62; 0.64)	0.69 (0.68; 0.70)	0.72 (0.71; 0.73)

Discussion

In this population-based study in Ontario, Canada, we found that frailty was strongly predictive of COVID-19 mortality regardless of vaccination status. Despite substantial home-to-home variation in mortality, the home-level characteristics we examined were not significantly associated with COVID-19 mortality.

Whilst a significant amount of research has been conducted regarding COVID-19 in LTC homes, little work has examined resident and home-level characteristics simultaneously in a multi-level analysis. The novelty of this work lies in our identification of significant home-to-home variation in the risk of COVID-19 death amongst LTC residents that is not explained by home-level characteristics previously attributed to COVID-19 outcomes. Another Canadian study early in the pandemic found that home-level characteristics and geographic incidence of SARS-CoV-2 infection influenced COVID-19 mortality in LTC residents. However, this work did not account for clustering at the home level [1]. When we accounted for clustering, home-level characteristics were no longer influential, suggesting that the home-level characteristics we included do not meaningfully affect death after infection and that other factors are responsible for the home-to-home variation we observed. Given that other international countries have similarities in the structure of LTC such as governmental regulation and inspections, public funding, and operated

Table 4. Multi-level logistic regression models with resident and home-level covariates for the odds ratio of death within 30 days, post-vaccine period (1 January 2021 to 31 August 2021), $n = 3{,}655$.

OR (95% CI)	Model 1: null	Model 2: resident and home characteristics	Model 3: Hubbard Frailty Index, residents and home characteristics
RESIDENT CHARACTERISTICS			
Male sex	–	1.70 (1.41; 2.04)	1.78 (1.48; 2.15)
Age group, years			
<65	–	*Reference*	*Reference*
65–69	–	0.85 (0.44; 1.64)	0.80 (0.41; 1.56)
70–74	–	1.19 (0.67; 2.10)	1.11 (0.63; 1.97)
75–79	–	1.97 (1.19; 3.27)	1.75 (1.05; 2.93)
80–84	–	2.44 (1.50; 3.96)	2.16 (1.32; 3.53)
85–89	–	2.84 (1.77; 4.54)	2.50 (1.55; 4.03)
90–94	–	3.64 (2.27; 5.85)	3.19 (1.98; 5.15)
95+	–	3.48 (2.10; 5.77)	3.19 (1.91; 5.31)
Hubbard Frailty Index (Δ 0.1)	–	–	1.45 (1.33; 1.59)
HOME CHARACTERISTICS	–		
Home size			
Small: <97 beds	–	*Reference*	*Reference*
Medium: 97–160 beds	–	1.02 (0.71; 1.47)	1.04 (0.71; 1.53)
Large: 160+ beds	–	0.91 (0.62; 1.33)	0.97 (0.65; 1.45)
Rural homes	–	1.33 (0.83; 2.15)	1.29 (0.78; 2.14)
Home region			
Central	–	*Reference*	*Reference*
East	–	1.31 (0.89; 1.92)	1.22 (0.82; 1.83)
North	–	1.74 (0.77; 3.91)	1.98 (0.85; 4.60)
Toronto	–	0.73 (0.44; 1.19)	0.82 (0.49; 1.38)
West	–	1.34 (0.97; 1.86)	1.30 (0.93; 1.83)
Chain ownership			
1 home, not in a chain	–	*Reference*	*Reference*
2–9 homes	–	0.94 (0.64; 1.39)	0.94 (0.63; 1.41)
10–19 homes	–	1.10 (0.69; 1.74)	1.01 (0.62; 1.64)
20+ homes	–	0.96 (0.58; 1.59)	0.99 (0.58; 1.67)
Home ownership type			
Municipal	–	*Reference*	*Reference*
Private non-profit	–	0.88 (0.54; 1.37)	0.99 (0.63; 1.57)
Private for-profit	–	1.04 (0.69; 1.57)	1.26 (0.81; 1.94)
Crowding index			
Low < 2.0	–	*Reference*	*Reference*
High 2.0–4.0	–	0.96 (0.73; 1.27)	0.98 (0.73; 1.31)
HOME VARIABILITY STATISTICS			
Covariance estimate (95% CI)	0.29 (0.18; 0.52)	0.22 (0.13; 0.43)	0.26 (0.16; 0.50)
SE	0.076	0.065	0.074
ICC	0.080	0.062	0.073
MOR (95% CrI)	1.66 (1.50; 1.99)	1.55 (1.41; 1.87)	1.62 (1.46; 1.96)
AUC/C statistic (95% CI)	0.71 (0.69; 0.73)	0.71 (0.69; 0.73)	0.74 (0.72; 0.76)

through a mix of private and public companies, an important priority area for further research includes identifying what characteristics impact home-level variation in mortality. These could include other home-level characteristics such as staffing ratios, staffing roles, staff vacancies, culture, leadership, medical competence, specialist support and infection control, or characteristics of the local community such as the severity of local community outbreaks. A high-quality workforce is needed in LTC, and the COVID-19 pandemic only worsened availability of limited personnel across multiple countries [32]. All post-industrial nations face similar challenges as Canada with high costs, a workforce that is underpaid and receives inadequate training, workforce shortages and concerns with the quality of care delivered [33–37]. In addition, policymakers and administrators should consider how to respond to the home-level characteristics known to be associated with adverse outcomes amongst residents. For example, other Canadian work found that infections from LTC staff and a shortage of nurses were associated with death amongst residents [14, 38]. In the United States, underlying racial inequality has been found to impact infection and death and was associated with larger home size and community-level outbreaks [39, 40]. Adequate staffing mix and ratios and reducing racial disparities with better quality in care and sufficient resources may reduce the overall home-to-home variation in the risk of

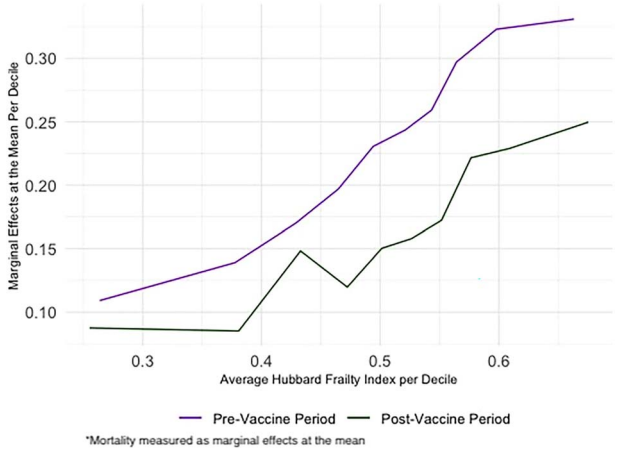

Figure 1. Mortality by average frailty index per decile, across study periods*.

COVID-19 death. These findings may be applicable in LTC homes for other respiratory infections beyond COVID-19, such as pneumonia and influenza.

We found that frailty was predictive of COVID-19 death in LTC residents across study periods, regardless of vaccination status and the type of frailty measure calculated. We applied frailty measures designed for acute care, home care and LTC populations and found similar results. Our findings also illustrate that residents at all frailty levels exhibited a higher risk of death pre-vaccine compared to the post-vaccine period. However, even though mortality risk decreased, the effect of frailty was not statistically significant pre- and post-vaccine availability. This underscores that frailty is a robust predictor of mortality that is not sensitive to the reduction in risk brought about by the COVID-19 vaccine and can be used to understand baseline risk for poor outcomes [4]. Outside the COVID-19 context, other research shows that frailty has predictive utility for overall survival and offers good prognostic value beyond medical acuity in older adults [41]. It has also been proposed that frailty be considered during shared decision-making about end-of-life care directives [42]. Our work supports this other research in highlighting that clinical decision-makers consider frailty over other variables, such as age, which lose prognostic value after the consideration of frailty [41]. Frailty should be used to have discussions about infection prevention and management, end-of-life wishes, life support withdrawal and decision-making regarding transfers by targeting frail older adults as appropriate and relevant. Most frailty measures are a continuous risk scale that can support health monitoring since they are easily calculated from standardised data available in LTC homes. Our results highlight the practicality of using existing data for risk identification and resident and/or family communication. Furthermore, the use of the interRAI MDS 2.0 assessment in this study increases the applicability of this study as this comprehensive minimum dataset is used worldwide across LTC homes allowing for straightforward comparisons between jurisdictions [43]. This is a powerful tool as clinically it can support the identification of frailty in residents in a consistent manner that can be applied to improve resident care, support care team effectiveness, and monitor organisational and system-level effectiveness [43, 44].

Limitations

Our data should be considered with certain limitations. Our study did not have all home-level characteristics that could explain home-to-home variation, such as staffing models (hours of care and the number of different professionals working), care provision models and SARS-CoV-2 infection rates amongst staff. We also do not have prior COVID-19 community outbreak status at the home level, which could be a reason for the home-to-home variation. Our cohort included only those with symptomatic infections and thus may be incomplete. Finally, we did not have resident-level vaccination administration information for LTC residents due to record-keeping procedures used at the time of vaccine delivery. The inclusion of resident-level vaccine data would improve the robustness of our findings by considering the time-dependent effect of vaccine administration.

Conclusions

Frailty is a robust and consistent predictor of COVID-19 mortality risk in LTC residents post-SARS-CoV-2 vaccination. Although we found significant home-level variation in the risk of death, we did not find any significant home-level predictors of mortality. More work is needed to identify the characteristics underlying the variation in COVID-19 mortality rates across LTC homes.

Supplementary Data: Supplementary data mentioned in the text are available to subscribers in *Age and Ageing* online.

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