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A population-based study on the impact of social determinants of health on time to treatment of stage I lung cancer in Ontario, Canada

Nader M Hanna¹, Saad Shakeel², Gileh-Gol Akhtar-Danesh³, Christian Finley¹ and Noori Akhtar-Danesh^{4*}

Abstract

Background Timely treatment of Stage I non-small cell lung cancer (NSCLC) is essential to improving outcomes, yet disparities persist in access to treatment across patient populations. This study aimed to assess the association between social determinants of health (SDOH) and time to treatment for patients with Stage I NSCLC in Ontario, Canada.

Methods We conducted a population-based retrospective cohort study using linked administrative databases. Adults diagnosed with Stage I lung cancer between 2007 and 2023 were included if they underwent either surgery or radiotherapy. Patients receiving chemotherapy, or surgery and radiotherapy were excluded. Flexible parametric models were used to evaluate associations between SDOH and time to treatment, stratified by treatment modality.

Results Among 10,734 patients with Stage I NSCLC, 7,366 (68.6%) received surgery only and 3,022 (28.2%) received radiotherapy only. Only 346 (3.2%) received both surgery and radiation. Increased time to treatment was significantly associated with advanced age (> 80 years: HR = 0.61, $p < 0.001$), higher comorbidity burden (> 5 comorbidities: HR = 0.80, $p = 0.004$), and being virtually rostered with a family physician (HR = 0.91, $p = 0.001$). Patients in the lowest neighbourhood income quintile had significantly longer time to treatment compared to higher quintiles (Q5: HR = 1.13, $p < 0.001$). Those living 50–100 km from a cancer centre experienced longer time to treatment (HR = 0.93, $p = 0.011$), as did patients treated in the Eastern region (HR = 0.79, $p < 0.001$) compared to those in the Central region. Time to treatment shortened over time, with improvements seen in 2015–2023 compared to 2007–2009.

Conclusions This study identifies age, comorbidity, socioeconomic status, geographic distance, and regional location as key SDOH associated with prolonged time to treatment for Stage I NSCLC in Ontario. These findings highlight ongoing inequities in cancer care and underscore the need for targeted policy and system-level interventions to improve timely treatment for vulnerable populations.

Keywords Social determinants of health, Lung cancer, Time to treatment, Health services research, Population-level research

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Background

Lung cancer remains the leading cause of cancer-related death in Canada [1] and worldwide [2], with early detection and timely treatment being critical to improving survival [3]. For patients with Stage I non-small cell lung cancer (NSCLC), surgical resection is the recommended first-line treatment, with radiotherapy offered to those who are medically inoperable, or those who decline surgical resection [4]. Delays in initiating treatment have been associated with disease progression and worse outcomes. However, access to timely care is not distributed equally across populations [5].

Emerging evidence suggests that social determinants of health (SDOH) may influence time to treatment. Older adults and those with comorbidities often require more comprehensive preoperative evaluation and additional medical optimization [6]. Socioeconomic status (SES) is a well-established factor in access to oncological treatment [7]. Those living in lower-income neighbourhoods may experience barriers such as limited transportation, reduced health literacy [8], and competing life priorities that contribute to longer wait times. Geographic factors also play a critical role. In Ontario, patients residing farther from regional cancer centres may experience care delays due to logistical challenges [9], despite travel assistance programs. Additionally, regional variation in healthcare infrastructure and specialist availability has been demonstrated in other cancer sites [10, 11] and may result in unequal access to timely lung cancer care.

Understanding how these social and structural factors affect time to treatment is essential for designing equitable cancer care delivery systems. Ontarians enjoy free healthcare at the point of entry into the system, but thoracic surgery services are regionalised to only 15 centres. Access therefore is universal but perhaps not equitable. This study aims to evaluate the relationship between social determinants of health and time to treatment amongst patients with Stage I lung cancer in Ontario using linked, population-based administrative health data.

Methods

Study design and cohort

This was a retrospective cohort analysis based on routinely collected population-level health data from Ontario, Canada, which has a population exceeding 16 million. We used linked administrative datasets housed at ICES (formerly known as the Institute for Clinical Evaluative Sciences), which enable individual-level data linkage across multiple sources. Adult patients with lung cancer diagnosed between January 2007 and December 2023 were identified using the Ontario Cancer Registry (OCR). Eligible cases were defined by ICD-O codes C34.0, C34.1, C34.2, C34.3, C34.8, and

C34.9, corresponding to various sites within the lung. Only patients with Stage I disease were included (using the *beststage* variable that prioritises pathological stage where available). Treatment modality was determined through procedure codes: radiotherapy was identified using the Activity Level Reporting (ALR) database, while surgical interventions were captured using the Canadian Classification for Health Interventions (CCI) codes. Patients were excluded if they received chemotherapy, had a history of malignancy within five years before diagnosis, developed a new cancer within five years following the index lung cancer diagnosis, or the recorded date of treatment was the same as the date of diagnosis (to restrict the study population to those with an appropriate treatment interval). The Hamilton Integrated Research Ethics Board approved the study protocol (HiREB #17274).

Data sources

The OCR records information on patient demographics, cancer diagnoses, and mortality, capturing more than 98% of all new cancer cases in Ontario [12]. Data from the OCR were linked with several administrative health databases to extract details on demographics, clinical outcomes, and relevant covariates. Radiotherapy-related data, including dosage, timing, and treatment dates, were obtained from the ALR database. Surgical procedures, including the type and timing of lung resections were identified using CCI codes. Additional demographic characteristics and covariates were drawn from multiple sources, including the Registered Persons Database (RPDB), Ontario Health Insurance Plan (OHIP) claims, the Same Day Surgery (SDS) and Discharge Abstract Database (DAD), the Local Health Integration Network (LHIN) data, the Postal Code Conversion File (PCCF), the Ontario Marginalization Index (ON-Marg), the National Ambulatory Care Reporting System (NACRS), and the Immigration, Refugees and Citizenship Canada (IRCC) Permanent Resident database.

Covariates and outcomes

The primary outcome was time to treatment from date of diagnosis. We further divided the analysis into time to radiotherapy and time to surgery. Demographic characteristics included were age, sex, comorbidity burden, frailty, and year of diagnosis. Comorbidity was assessed using OHIP and DAD claims data from 6 to 30 months prior to diagnosis and categorized through the Johns Hopkins ACG System [13], which was also applied to calculate frailty scores. Ontario's 14 Local Health Integration Networks were consolidated into four regions: Central, Southwest, East, and North. Measures of SDOH included household and neighbourhood income, attachment to a family physician, distance to the nearest

Table 1 Distribution of baseline demographics by treatment received

	Surgery (N = 7366) [n (%)]	Radiation (N = 3003) [n (%)]
Age groups (years)		
<50	298 (4.1)	9 (0.3)
50–64	1071 (14.5)	140 (4.6)
64–75	2516 (34.2)	571 (19.0)
75–84	2688 (36.5)	1199 (39.9)
≥85	793 (10.8)	1084 (36.1)
Sex		
Male	3007 (40.8)	1391 (46.3)
Female	4359 (59.2)	1612 (53.7)
Comorbidities		
0	2427 (55.8)	758 (38.5)
1–2	1529 (35.2)	808 (41.1)
3–4	311 (7.2)	301 (15.3)
≥5	82 (1.9)	100 (5.1)
Frailty Index		
No	7130 (94.6)	2518 (83.9)
Yes	408 (5.4)	485 (14.2)
Family Physician		
Rostered	6420 (85.2)	2521 (84.0)
Virtually rostered	969 (12.6)	392 (13.1)
Not rostered	149 (1.9)	90 (3.0)
Immigrant		
No	6858 (91.0)	2908 (96.8)
Yes	680 (9.0)	95 (3.2)
Household Income		
Quintile 1	1079 (14.4)	246 (8.3)
Quintile 2	1299 (17.3)	478 (16.1)
Quintile 3	1523 (20.4)	563 (19.0)
Quintile 4	1500 (20.0)	685 (23.1)
Quintile 5	2083 (27.8)	995 (33.5)
Neighbourhood Income		
Quintile 1	1643 (21.8)	810 (27.1)
Quintile 2	1615 (21.5)	697 (23.3)
Quintile 3	1467 (19.5)	557 (18.7)
Quintile 4	1439 (19.2)	477 (16.0)
Quintile 5	1352 (18.0)	446 (14.9)
Distance		
<50 km	5898 (78.3)	2124 (70.9)
50–100 km	1175 (15.6)	629 (21.0)
>100 km	456 (6.0)	244 (8.1)
Year		
2007–2009	1227 (16.6)	508 (16.9)
2010–2014	2271 (30.8)	1183 (39.4)
2015–2019	2770 (37.5)	1117 (37.2)
2020–2023	1098 (14.9)	195 (6.5)
LHIN		
Central	2464 (32.7)	573 (19.1)
Southwest	2170 (28.8)	775 (25.8)
Eastern	2063 (27.4)	1205 (40.2)
Northern	836 (11.1)	448 (14.9)
Recent Immigrant		
No	7455 (98.9)	2995 (99.7)
Yes	83 (1.1)	8 (0.3)

N Number, % Percentage, km Kilometre, LHIN Local Health Integrated Network

regional cancer centre, and immigration status. Individuals born outside of Canada were defined as immigrants. Those who had arrived in Canada within five years of diagnosis were classified as recent immigrants.

Statistical analysis

Descriptive statistics were reported based on mean and standard deviation for continuous variables, and frequency and percentage for categorical variables. We used flexible parametric models for the time to treatment analysis [14]. We created three models: (1) time to any treatment received (radiotherapy or surgery), (2) time to surgery, and (3) time to radiotherapy. We included the following in the models: age, sex, comorbidity, frailty, year of diagnosis, household and neighborhood income, access to family physician, distance, and region, using a forward stepwise approach in that order. The flexible parametric model was performed using the *stpm2* program for Stata package [15]. Statistical analyses were conducted using Stata/MP 15.1 (Stata Corporation, College Station, TX).

Results

A total of 10,734 patients with Stage I lung cancer were identified (Table 1). There were 346 patients who received both surgery and radiation, and these were excluded from all analyses. Those that received surgery or radiation therapy only were included in this study with a mean (SD) age of 70.0 (10.3) years. Females comprised 57.3% of the study population. Of these, 7,366 (68.6%) received surgery alone – the mean (SD) age was 67.9 (10.0) years and females comprised 59.2% of the surgical group. There were 3,003 (28.0%) who received radiotherapy alone – the mean (SD) age was 75.4 (8.8) years and females comprised 53.6%.

Table 2 shows the associations between the covariates with the time to any treatment using a flexible parametric survival analysis. The results are based on hazard ratio (HR) with the event of interest being receipt of either surgery or radiotherapy. The time to treatment significantly increased with advancing age, longest for patients aged ≥ 80 years (HR = 0.60, *p*-value < 0.001), compared to the reference group of < 50 years old. The likelihood of a shorter time to treatment significantly increased over time between 2015–2019 and 2020–23, compared to 2007–09 (HR = 1.20, *p*-value < 0.001; HR = 1.15, *p*-value < 0.001, respectively). Increasing neighbourhood income was associated with significantly shorter time to treatment for quintiles 4 and 5 compared to the lowest quintile (HR = 1.09, *p*-value = 0.004; HR = 1.12, *p*-value < 0.001, respectively). Patients living 50–100 km from the nearest regional cancer centre had significantly longer time to treatment, compared to

Table 2 Results of flexible parametric analysis for any treatment received

	Hazard Ratio	95% CI	p-value
Age groups (years)			
<50 (reference)	---	---	---
50–64	0.89	0.79–1.00	0.067
64–75	0.80	0.71–0.89	<0.001
75–84	0.71	0.63–0.79	<0.001
≥85	0.60	0.53–0.68	<0.001
Sex			
Male (reference)	---	---	---
Female	1.01	0.97–1.05	0.568
Family Physician			
Rostered (reference)	---	---	---
Virtually rostered	0.91	0.86–0.96	0.001
Not rostered	0.98	0.86–1.12	0.791
Neighbourhood Income			
Quintile 1 (reference)	---	---	---
Quintile 2	1.02	0.97–1.08	0.464
Quintile 3	1.04	0.97–1.10	0.250
Quintile 4	1.09	1.02–1.16	0.004
Quintile 5	1.12	1.06–1.20	<0.001
Distance			
<50 km (reference)	---	---	---
50–100 km	0.93	0.88–0.98	0.011
>100 km	0.93	0.85–1.01	0.101
Year			
2007–2009 (reference)	---	---	---
2010–2014	0.99	0.94–1.05	0.727
2015–2019	1.20	1.14–1.27	<0.001
2020–2023	1.15	1.07–1.24	<0.001
LHIN			
Central (reference)	---	---	---
Southwest	0.94	0.89–0.99	0.027
Eastern	0.79	0.75–0.83	<0.001
Northern	1.03	0.95–1.10	0.498

CI Confidence interval, km Kilometre, LHIN Local Health Integrated Network

those < 50 km away (HR = 0.93, *p*-value = 0.01). Compared to the Central region, those being treated in the Southwest (HR = 0.94, *p*-value = 0.027) and Eastern regions (HR = 0.79, *p*-value < 0.001) had a significantly longer time to treatment. Being on a virtual roster for a family physician was associated with a significantly longer time to treatment (HR = 0.91, *p*-value = 0.001) compared to those patients with a family physician. In the model that included comorbidity, those with comorbidities (3–4; ≥5) had a significantly longer time to treatment compared to patients with no comorbidities (HR = 0.84, *p*-value < 0.001; HR = 0.80, *p*-value = 0.004, respectively). Frailty, household income, and immigration status were not found to be significant factors for the model and were therefore excluded from this analysis.

Table 3 depicts the association between covariates and time to surgery. The time to surgery significantly increased for age groups 70–79 and ≥ 80, compared to < 50 years (HR = 0.84, *p*-value = 0.005; HR = 0.77,

Table 3 Results of the flexible parametric analysis for surgery

	Hazard Ratio	95%CI	p-value
Age groups (years)			
<50 (reference)	---	---	---
50–64	0.96	0.84–1.08	0.500
64–75	0.89	0.79–1.01	0.061
75–84	0.84	0.74–0.95	0.005
≥85	0.77	0.68–0.88	<0.001
Sex			
Male (reference)	---	---	---
Female	1.01	0.96–1.05	0.699
Family Physician			
Rostered (reference)	---	---	---
Virtually rostered	0.91	0.85–0.97	0.006
Not rostered	0.98	0.83–1.15	0.806
Neighbourhood Income			
Quintile 1 (reference)	---	---	---
Quintile 2	0.99	0.92–1.06	0.760
Quintile 3	1.00	0.93–1.07	0.929
Quintile 4	1.07	0.99–1.15	0.064
Quintile 5	1.10	1.01–1.18	0.015
Distance			
<50 km (reference)	---	---	---
50–100 km	0.94	0.88–1.00	0.076
>100 km	0.90	0.81–1.01	0.083
Year			
2007–2009 (reference)	---	---	---
2010–2014	1.00	0.93–1.07	0.973
2015–2019	1.13	1.05–1.20	0.001
2020–2023	1.04	0.96–1.13	0.323
LHIN			
Central (reference)	---	---	---
Southwest	0.99	0.93–1.06	0.954
Eastern	0.79	0.73–0.84	<0.001
Northern	1.07	0.98–1.17	0.132

CI Confidence interval, km Kilometre, LHIN Local Health Integrated Network

p-value < 0.001, respectively). The likelihood of a shorter time to surgery significantly increased in 2015–19, compared to 2007–09 (HR = 1.13, *p*-value = 0.001). Increasing neighbourhood income was associated with significantly shorter time to surgery, but only for the highest quintile compared to the lowest (HR = 1.10, *p*-value = 0.015); others were non-significant. Compared to the Central region, patients from the Eastern region had a significantly longer time to surgery (HR = 0.79, *p*-value < 0.001), with patients in the other geographical areas having no statistically significant differences. Being on a virtual roster for a family physician was associated with significantly longer time to surgery (HR = 0.91, *p*-value = 0.006) compared to the patients fully rostered with a family physician. Those with 1–2 comorbidities had significantly shorter time to surgery compared to the patients with no comorbidities (HR = 1.15, *p*-value < 0.001). Frailty, household income, and immigration status were not significant contributors to the model and were not included in this analysis.

Table 4 illustrates the association between the covariates and time to radiotherapy. Age, sex, comorbidities, frailty, neighborhood income, household income, immigration status, distance, and access to family physician were not significant contributors to the model, hence were not included in this analysis. The likelihood of a shorter time to radiotherapy significantly increased for 2010–14 and 2015–19, compared to 2007–09 (HR = 1.11, p-value = 0.049; HR = 1.47, p-value < 0.001, respectively). Patients receiving care in the Northern region had significantly shorter time to radiotherapy (HR = 1.25, p-value < 0.001) compared to the Central region, with no significant differences for the other regions.

Table 5 depicts the median time to treatment based on all analysed covariates.

Discussion

The key finding of this population-based study is that social determinants of health negatively impact the time to treatment for stage I lung cancer. Those who had a longer time to treatment included patients virtually rostered with a family physician (compared to those fully rostered), patients living in the lowest neighbourhood income quintile, and those living up to 100 km away from the nearest regional cancer centre. Additionally, time to treatment increased with advanced age and was longer for people receiving care in the Eastern part of the province compared to those in the central LHINs. Time to treatment decreased from 2007 to 2009 to 2020–2023.

Univariable analysis (Table 1) revealed a temporal trend from 2007 to 2023, marked by a growing proportion of patients undergoing surgery and a corresponding decline in those treated with radiotherapy. This pattern likely represents the progressive adoption of evidence-based clinical guidelines by surgical and oncology practitioners. The years were grouped in this way to align with key system-level events: the regionalization of thoracic surgery services between 2007 and 2010 [16, 17], and the onset of the COVID-19 pandemic beginning in 2019. The

effects of the COVID-19 pandemic on cancer treatment delivery were investigated by Shah [18] who reported a 29% decrease in cancer operations and a 15% decline in radiotherapy utilization during the pandemic compared to the pre-pandemic period. These results are consistent with the trends observed in our study.

Unsurprisingly, with advanced age came a greater likelihood of receiving radiotherapy than surgery. Whilst guidelines [4] still favour surgical resection over radiotherapy for patients with Stage I lung cancer that are surgical candidates, some recent studies [19–22] have demonstrated no difference in survival between these treatment modalities. Elderly patients with a presumed shorter life expectancy may wish to avoid the potential of postoperative complications, pain, and decrease in baseline function that is associated with a surgical procedure.

This study also found that patients living in the Eastern part of the province had a longer time to treatment (whether surgery or radiotherapy) (Fig. 1A) and had a longer time to surgery (Fig. 1B), compared to the Central part of the province. Those living in the Western part of the province had the shortest time to radiation treatment (Fig. 1C), whereas those in the Central part had the longest time to treatment (Tables 4 and 5). Patients residing in central regions of Ontario may experience longer intervals before initiation of radiation therapy for several reasons. First, these regions contain the province’s largest tertiary cancer centres and therefore manage disproportionately high patient volumes and more complex cases referred from other regions. High demand for radiation therapy resources can create capacity constraints that contribute to treatment delays. Additionally, workforce availability, including radiation oncologists, medical physicists, and radiation therapists, has previously been identified as a contributor to regional variation in radiotherapy wait times in Ontario [23]. Regionalization aimed to improve equity in access to specialized thoracic surgery care by ensuring that all patients, regardless of where they lived in Ontario, could receive high-quality treatment [24]. An Ontario-based study published in 2013 [17] highlighted the potential impact of this policy shift: whilst median wait times for lung cancer treatment did not significantly improve between 2007 and 2011, there was a meaningful reduction in 30-day postoperative mortality following pneumonectomy. A more contemporary study [25] corroborated these outcomes. Our findings suggest that while centralizing complex oncological care may enhance treatment safety, system-wide efficiency and access to care remain a challenge.

Older age was associated with a longer wait time for any treatment and specifically for surgery. One possible explanation is that older patients often need additional preoperative assessments compared to younger individuals receiving the same treatment [6]. These extra

Table 4 Results of the flexible parametric analysis for radiotherapy

	Hazard Ratio	95%CI	p-value
Year			
2007–2009 (reference)	---	---	---
2010–2014	1.11	1.00–1.23	0.049
2015–2019	1.47	1.32–1.63	< 0.001
2020–2023	1.13	0.96–1.34	0.133
LHIN			
Central (reference)	---	---	---
Southwest	0.99	0.88–1.11	0.871
Eastern	1.08	0.98–1.19	0.122
Northern	1.25	1.10–1.41	< 0.001

LHIN Local Health Integrated Network

Table 5 Median time to treatment based on baseline demographics

	Time to Treatment (days) [25th -75th percentile]	Time to Surgery (days) [25th -75th percentile]	Time to Radiation (days) [25th -75th percentile]
Age groups (years)			
<50	51 [33–72.5]	50 [31–70]	93 [70–163]
50–64	55 [36–82]	51 [35–77]	91 [58–127]
64–75	61 [40–89]	56 [36–81]	86 [62–126]
75–84	65 [44–96]	57 [38–83]	88 [64–125]
≥85	74 [52–105]	62 [41–87]	84 [62–115]
Sex			
Male	64 [43–93]	56 [37–82]	84 [62–119]
Female	63 [42–92]	56 [37–81]	89 [63–124]
Comorbidities			
0	63 [42–92]	57 [38–82]	87 [62–122]
1–2	62 [40–91]	52 [34–76]	85 [61–119]
3–4	71 [47.5–102.5]	54 [34–82]	85 [66–124]
≥5	76 [51.5–105]	55.5 [31–83]	91 [64.5–127]
Frailty Index			
No	63 [42–92]	56 [36–81]	86 [63–121.5]
Yes	75 [51–106]	62 [40–84]	88 [62–121]
LHIN			
Central	58 [38–86]	53 [35–76]	90 [66–128]
Southwest	63 [41–92]	55 [35–77]	91 [66–123]
Eastern	72 [49–102]	64 [43–92]	87 [59–122]
Northern	62 [42–86]	54 [35–77]	76 [58–106]
Family Physician			
Rostered	63 [42–92]	56 [36–80]	86 [62–121]
Virtually rostered	66 [43–99]	58 [37–87.5]	90 [64–125]
Not rostered	66 [44–93]	57 [40–82]	84 [54–111]
Immigrant			
No	64 [42–93]	56 [36–81]	86 [62–121]
Yes	60 [41–91]	55 [39–82]	99 [75–140]
Household Income			
Quintile 1	61 [40–87]	55.5 [35–78]	91 [65–128.5]
Quintile 2	62 [42–90]	55 [36–78]	84 [62–125.5]
Quintile 3	64 [42–92]	57 [36–83]	85 [62–118]
Quintile 4	64 [44–93.5]	56 [38–82]	85 [62–119]
Quintile 5	65 [43–95]	56 [38–84]	88 [62–122]
Neighbourhood Income			
Quintile 1	65 [44–97]	56 [38–84]	88 [63–124]
Quintile 2	65 [43–93]	57 [38–83]	84 [62–118.5]
Quintile 3	64 [42–95]	57 [37–83]	87 [62–120.5]
Quintile 4	62 [41–90]	55 [36–80]	86 [64–127]
Quintile 5	61 [41–88]	54 [36–76]	85.5 [63–119]
Distance to cancer centre			
<50 km	63 [41–91]	55 [36–80]	86 [63–121]
50–100 km	69 [46–101]	59 [41–86]	88 [60–124]
>100 km	68 [45–94]	57 [39–83]	82.5 [63–114]
Year			
2007–2009	65 [42–101]	55 [36–84]	98 [72–135]
2010–2014	69 [46–99]	58 [37–84]	92 [66–128]
2015–2019	61 [42–86]	55 [37–77]	77 [56–107]
2020–2023	58 [38–88]	55 [36–82]	84 [61.5–128.5]
Recent Immigrant			
No	64 [42–92]	56 [37–81]	86 [62–121]
Yes	59 [41–80]	54.5 [41–78]	100.5 [74–146]

km Kilometre, LHIN Local Health Integrated Network

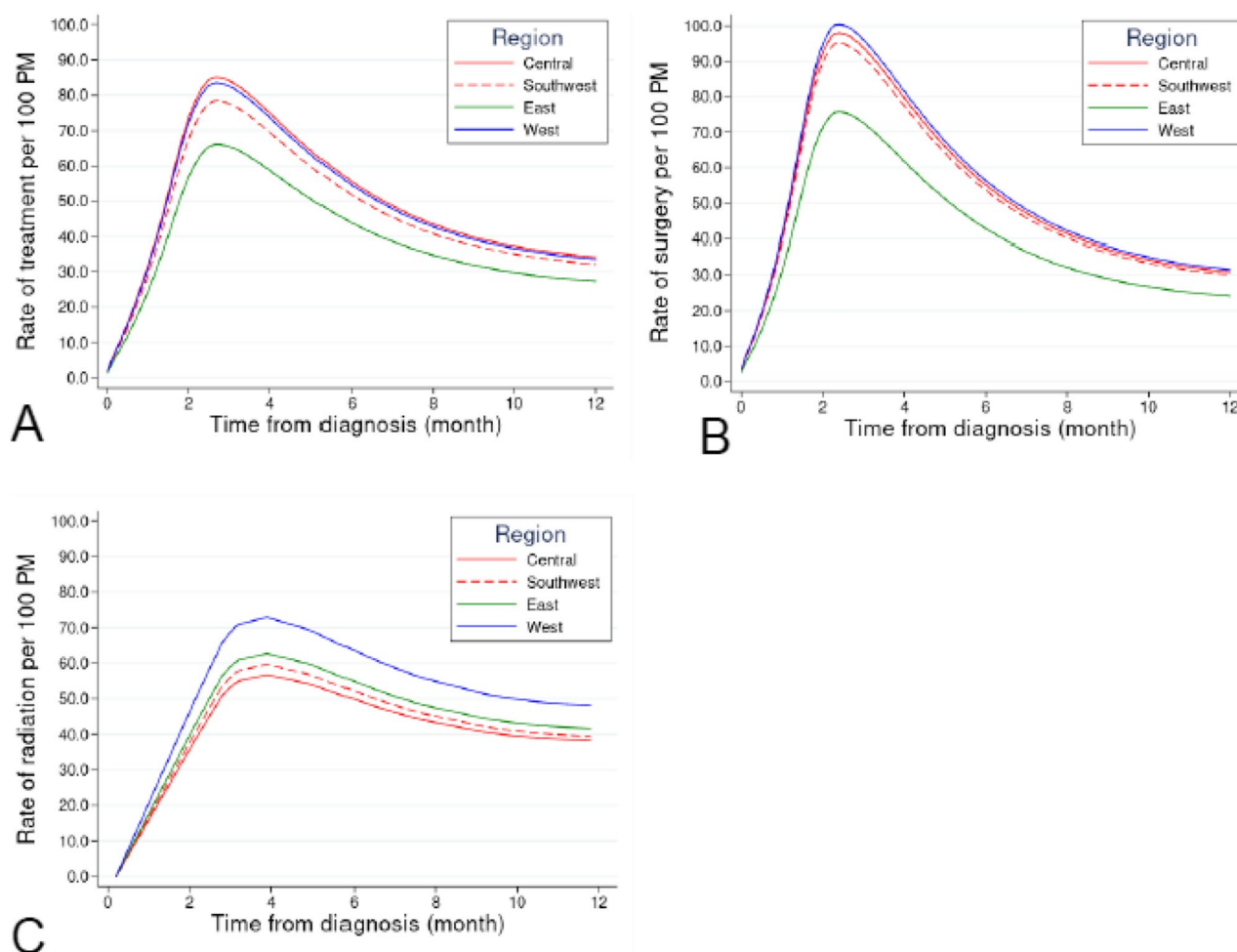


Fig. 1 **A** Trends in time to any treatment modality based on region (LHIN). **B** Trends in time to surgery as the first line of treatment based on region (LHIN). **C** Trends in time to radiation as the first line of treatment based on region (LHIN)

evaluations can postpone treatment initiation and, consequently, delay the scheduled treatment date until the necessary results are reviewed and addressed. This is also true of patients with comorbidities who had a longer time to any treatment (Fig. 2A) and to surgery (Fig. 2B). Our findings align with previous Canadian research showing a correlation between advancing age and prolonged wait times for cancer care [26–29].

Patients who lived between 50 and 100 km from a cancer centre had a longer time to any treatment (Fig. 3A) and a longer time to surgery (Fig. 3B) compared to those who lived within 50 km of a cancer centre. It is possible that these patients tried to group all their pretreatment appointments (consults and investigations) into only one or two days to reduce transport time, and that this resulted in postponing some of these appointments to a more convenient time. This association was not statistically significant when analyses were stratified by treatment modality. It is possible that stratification reduced the sample size within each treatment group, thereby

reducing statistical power to detect smaller differences. Additionally, the pathways leading to surgical versus radiotherapy treatment differ. Surgical care for lung cancer in Ontario is centralized to a limited number of thoracic surgery centres, whereas radiotherapy services are delivered through a broader network of regional cancer centres. Patients may also complete portions of their diagnostic workup closer to their residence before being referred for definitive treatment. As a result, geographic distance may influence the overall care pathway leading to treatment initiation but may have a less consistent effect once the treatment modality has been determined. Interestingly, patients who lived more than 100 km from a cancer centre did not have a longer time to treatment or time to surgery. It is unclear why this would be the case. Perhaps those living a greater distance away have special access to travel assistance and financial help [30]. One example is the “Air Daffodil” initiative by Canadian Cancer Society (CCS) [31] which helps by arranging flights and ground transportation to patients travelling 100 kms

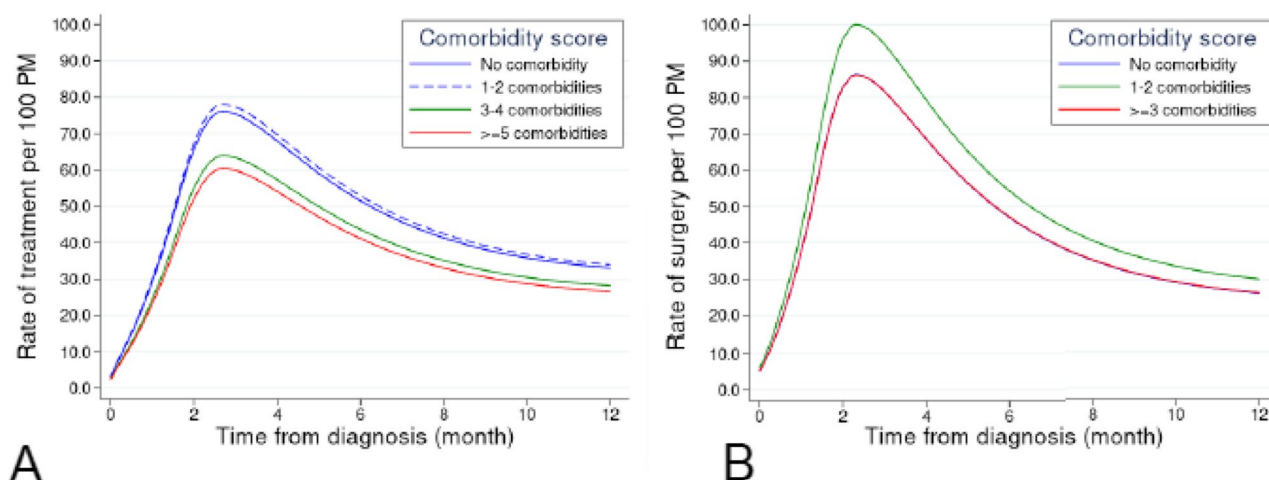


Fig. 2 **A** Trends in time to any treatment modality based on comorbidities. **B** Trends in time to surgery as the first line of treatment based on comorbidities

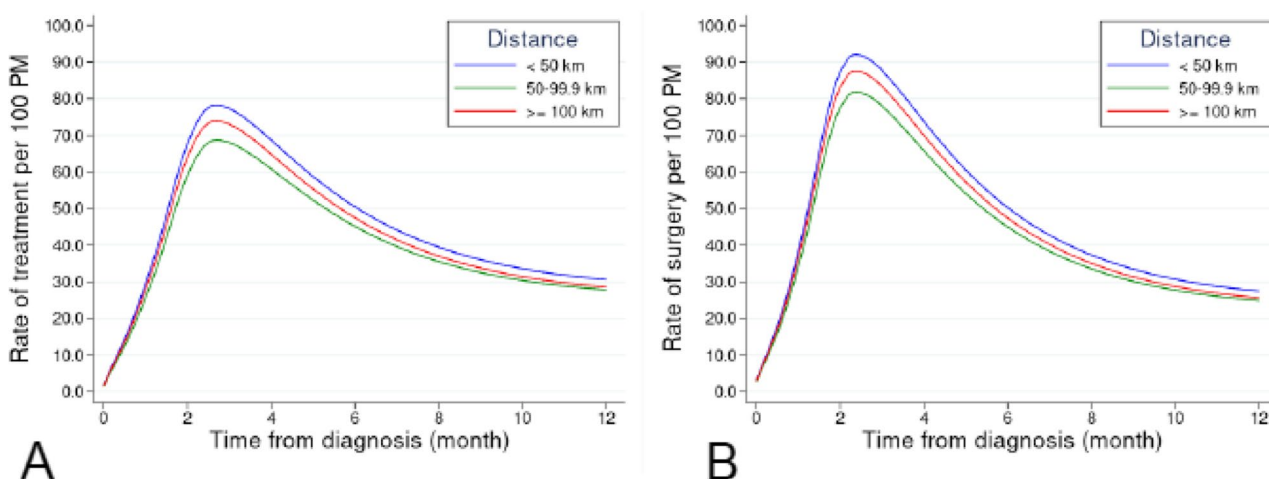


Fig. 3 **A** Trends in time to any treatment modality based on distance to the nearest cancer centre. **B** Trends in time to surgery as the first line of treatment based on distance to the nearest cancer centre

or more to a Cancer Centre or treatment location. The CCS pays the upfront cost of transportation and is reimbursed by the Ministry of Health through their Northern Health Travel Grant (NHTG) program. They also provide guidance on completing travel grants and liaise with the Ministry of Health on the patient's behalf. Others [32] have reported that those living in a rural area face either a delay (83%) or an acceleration (17%) in time to surgery, which is in line with the results of our own study.

Patients living in the highest income neighbourhoods had the shortest time to treatment (Fig. 4A) and time to surgery (Fig. 4B). Patients residing in lower-income neighbourhoods may face logistical and socioeconomic barriers that contribute to treatment delays. Limited access to reliable transportation can hinder timely attendance at diagnostic and treatment appointments, particularly when care is centralized in distant cancer centres. Public transit is generally not designed to carry patients to cancer centres, and many people living in a lower

income neighbourhood may not own a car. Others have demonstrated that travel times to treatment were consistently longer for patients who were more socioeconomically deprived [33]. Financial strain and competing responsibilities, such as employment insecurity or caregiving obligations, may further delay engagement with the healthcare system. Additionally, individuals from socioeconomically disadvantaged backgrounds often encounter greater difficulty navigating complex referral pathways and coordinating care, especially in the absence of formal support systems such as patient navigators or care coordinators [34, 35].

An important finding of our study was the association between virtual rostering with a family physician and longer wait times for surgery. In Ontario, virtual rostering occurs when patients are administratively assigned to a physician based on billing patterns, without a formal enrolment agreement. These patients often lack consistent primary care attachment, which has been shown to

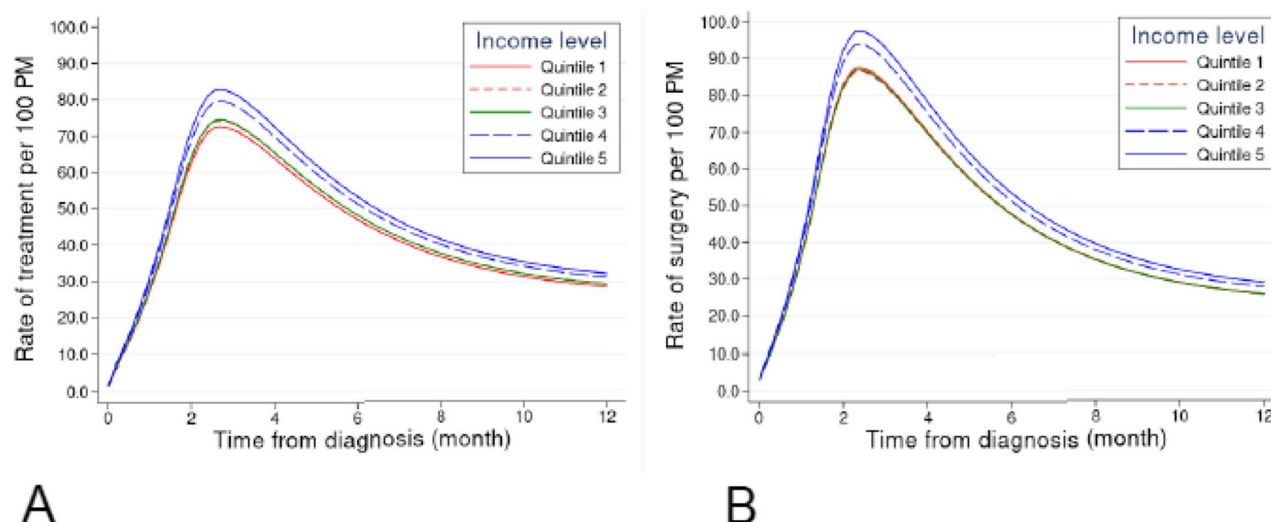


Fig. 4 **A** Trends in time to any treatment modality based on income. **B** Trends in time to surgery as the first line of treatment based on income

reduce continuity, weaken care coordination, and impair access to timely specialist referral [36]. In contrast, patients who are formally rostered typically benefit from stronger longitudinal relationships with a primary care provider, who may facilitate expedited investigations and more efficient navigation of the healthcare system. Virtual rostering may therefore serve as a proxy for weaker integration within primary care, leading to fragmented services and delays in treatment. Furthermore, patients without formal rostering are more likely to experience socioeconomic disadvantage, including lower income and housing instability, which may further exacerbate barriers to timely cancer care [37].

In Ontario, Health Quality Ontario [38] has outlined recommended targets for time intervals that they define as wait times. “Wait 1” is time from referral to surgical consultation, of which the recommendation is less than 21 days. “Wait 2” is time from decision to operate to the operation itself, of which the recommendation is less than 28 days. Thus, the maximum recommended time between referral and surgery is less than 49 days. Our study period begins with date of diagnosis, which is often before a referral is initiated, hence all timelines outlined in Table 5 are longer than 49 days. Nevertheless, we believe that the comparison between different levels within a single variable is a valuable metric to study, as reducing this timeline may impact oncological outcomes and will undoubtedly decrease anxiety related to waiting for cancer treatment [39].

The disparities in time to treatment identified in this study suggest several potential opportunities for system-level intervention. First, patient navigation programs may improve access to timely cancer treatment, by assisting patients with coordinating appointments, arranging transportation, and facilitating communication between

primary care providers and specialists. Such programs have been shown to reduce delays in cancer diagnosis and treatment by helping patients navigate complex healthcare systems [40]. Second, rapid-access lung cancer diagnostic assessment programs may shorten the treatment interval by consolidating imaging, biopsy, staging, and specialist consultation within coordinated care pathways. Third, targeted interventions aimed at older adults may help address the longer surgical wait times who frequently require additional preoperative assessments and medical optimization. Integrating geriatric oncology assessments or establishing expedited preoperative evaluation pathways for elderly patients may help reduce these delays while maintaining patient safety. Finally, strengthening primary care attachment may facilitate earlier specialist referral and improved care coordination. Patients who are virtually rostered may benefit from improved continuity with primary care providers or enhanced referral pathways that ensure timely access to oncology services.

This is the first population-based study of a cohort of Ontario patients with lung cancer that examined factors associated with the time to treatment. Using administrative healthcare databases and registries afforded us a “real-world” view of trends across the province. Previous studies were either single centre, did not examine lung cancer alone, or were conducted before or solely during the COVID-19 pandemic. Furthermore, we identified specific social determinants of health that impact time to treatment. There are some limitations of this study that warrant discussion. First, detailed social determinants such as access to reliable transportation or social support were not available in the data and may have influenced time to treatment. Additionally, we did not have information pertaining to fractionation, thus some patients

may have delayed treatment initiation to accommodate a longer treatment schedule. However, we restricted the cohort to Stage I NSCLC to ensure uniformity of treatment across the province. Second, the analysis was limited to individuals holding an Ontario health card, as only they are included in the administrative databases and registries used. Consequently, we were unable to assess time to treatment amongst those without provincial health coverage. Finally, although efforts were made to adjust for potential confounders, unmeasured variables may still have influenced the results. Despite our study's limitations, the use of a broad, unselected patient population from numerous healthcare centres across the province strengthens the generalizability of our findings and provides valuable insight into patients most at risk of a longer time to treatment for lung cancer.

Conclusion

This population-based study found that social determinants of health significantly affect time to treatment for Stage I lung cancer in Ontario. Delays were more common amongst patients who were older, more comorbid, lived in lower-income neighbourhoods, resided 50–100 km from cancer centres, or lived in the Eastern part of the province. These findings highlight persistent inequities in access to timely lung cancer treatment within a universal healthcare system. Addressing these disparities will likely require targeted health system interventions, including improved primary care attachment, expansion of patient navigation programs, enhanced coordination of diagnostic services, and strategies to mitigate geographic barriers to specialized cancer care.

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Authors' contributions

NH conceptualised the project, obtained and analysed the data, and wrote the manuscript. SS analysed the data, created the tables and figures, and reviewed the manuscript. GAD analysed the data and reviewed the manuscript. CF obtained funding, obtained and analysed the data, conceptualised the project, and reviewed the manuscript. NAD obtained the data, performed all statistical analyses, and reviewed the manuscript. All authors read and approved the final manuscript.

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Data availability

The dataset from this study is held securely in coded form at the ICES. While data sharing agreements prohibit the ICES from making the dataset publicly available, access may be granted to those who meet prespecified criteria for confidential access, available at www.ices.on.ca/DAS. The full dataset creation plan and underlying analytic code are available from the authors upon request, understanding that the computer programs may rely upon coding templates or macros that are unique to the ICES and are therefore either inaccessible or may require modification.

Declarations

Ethics approval and consent to participate

The Hamilton Integrated Research Ethics Board of McMaster University approved the study protocol (HiREB #17274). The study adhered to the Declaration of Helsinki. Informed consent was deemed unnecessary under Ontario Regulation 329/04, the Regulation to the Personal Health Information Protection Act (PHIPA).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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