The impact of patient travel time on disparities in treatment for early stage lung cancer in California

Chelsea A. Obrochta1,2, Humberto Parada, Jr.1,3, James D. Murphy3, Atsushi Nara4, Dennis Trinidad2, Maria Rosario (Happy) Araneta2, Caroline A. Thompson1,2,3,5*

1 San Diego State University, School of Public Health, San Diego, California, United States of America, 2 University of California San Diego, School of Medicine, La Jolla, California, United States of America, 3 University of California San Diego, Moores Cancer Center, La Jolla, California, United States of America, 4 Department of Geography, San Diego State University, San Diego, California, United States of America, 5 Department of Epidemiology, University of North Carolina Gillings School of Global Public Health, Chapel Hill, North Carolina, United States of America

* caroline.thompson@unc.edu

Abstract

Background
Travel time to treatment facilities may impede the receipt of guideline-concordant treatment (GCT) among patients diagnosed with early-stage non-small cell lung cancer (ES-NSCLC). We investigated the relative contribution of travel time in the receipt of GCT among ES-NSCLC patients.

Methods
We included 22,821 ES-NSCLC patients diagnosed in California from 2006–2015. GCT was defined using the 2016 National Comprehensive Cancer Network guidelines, and delayed treatment was defined as treatment initiation >6 versus ≤6 weeks after diagnosis. Mean-centered driving and public transit times were calculated from patients’ residential block group centroid to the treatment facilities. We used logistic regression to estimate risk ratios and 95% confidence intervals (CIs) for the associations between patients’ travel time and receipt of GCT and timely treatment, overall and by race/ethnicity and neighborhood socioeconomic status (nSES).

Results
Overall, a 15-minute increase in travel time was associated with a decreased risk of undertreatment and delayed treatment. Compared to Whites, among Blacks, a 15-minute increase in driving time was associated with a 24% (95%CI = 8%-42%) increased risk of undertreatment, and among Filipinos, a 15-minute increase in public transit time was associated with a 27% (95%CI = 13%-42%) increased risk of delayed treatment. Compared to the highest nSES, among the lowest nSES, 15-minute increases in driving and public transit times were associated with 33% (95%CI = 16%-52%) and 27% (95%CI = 16%-39%) increases in the risk of undertreatment and delayed treatment, respectively.
Conclusion
The benefit of GCT observed with increased travel times may be a ‘Travel Time Paradox,’ and may vary across racial/ethnic and socioeconomic groups.

Introduction
Favorable early-stage non-small cell lung cancer (NSCLC) prognosis is highly dependent on receipt of timely guideline-concordant treatment (GCT) [1]. Disparities in receipt of GCT have been observed among racial/ethnic minorities, those living in lower socioeconomic neighborhoods, and rural populations. An increased travel burden is associated with an increased diagnostic interval, more advanced disease at diagnosis, worse prognosis, and worse quality of life [2–27], as well as nonadherence to GCT [28] including undertreatment with surgery, radiation, chemotherapy, and adjuvant chemotherapy [4, 11, 19, 29–40]. However, the reported relationships between travel burden and cancer outcomes have been inconsistent. In previous studies, an increased travel burden was associated with a more rapid cancer diagnosis, lower overall mortality, and increased survival [40–43], while other studies show no association between travel burden and stage at diagnosis, treatment type, or long-term outcome [33, 44–47]. One study reported that women traveling farther distances to receive mastectomies were doing so after bypassing local options [20]; suggesting that an increased travel distance may be by choice, for some.

Receipt of cancer care may be influenced by a high travel burden as a result of residing long distances from treatment facilities or lack of private transportation. A higher travel burden has been documented for patients without a driver’s license or private vehicle [48] and for rural residents and non-Caucasians [44, 49–52]. On average, travel times are longer for public transportation compared to a private vehicle [49], however, there is some evidence that treatment facilities are favorably located closer to neighborhoods with the lowest household access to a private vehicle [50].

The objective of this study was to investigate the relative contribution of patients’ travel times to their treatment facilities on racial/ethnic and socioeconomic disparities in receipt of GCT among patients diagnosed with early-stage NSCLC in California. As higher travel burden has been observed in minority and lower socioeconomic groups, we hypothesized that the effect of travel time to treatment facilities on GCT differs by race/ethnicity and neighborhood socioeconomic status (nSES).

Methods
Data source
The California Cancer Registry (CCR) is a statewide population-based cancer surveillance program [53]. By law, all occurrences of cancer among Californians are required to be reported to the CCR, ensuring the population is representative of all of California [53]. Cancer details, demographics, and social and clinical details were collected by the CCR. County 2013 rural-urban continuum codes were ascertained from the United States (U.S.) Department of Agriculture. To determine the location of a patient’s cancer treatment facility, a list of complete addresses was compiled using Google and geocoded in ArcGIS PRO 2.4.

This study was reviewed and approved by Institutional Review Boards (IRBs) at San Diego State University, the University of California San Diego, and the California Department of Public Health Committee for the Protection of Human Subjects.
Study population
We included 23,571 patients diagnosed with first primary, stages I-II, NSCLC, as defined by the American Joint Committee of Cancer 7th edition, between 2006 and 2015, and alive at the time of diagnosis. Of these, we excluded patients due to the following reasons: missing lymph node (N) staging (n = 122) or missing date of diagnosis (n = 127), which were required to determine receipt of GCT; missing race (n = 43) or those who were classified as multiracial (n = 288) or other Hispanics (n = 9) due to race being required to assess differences by race, no validated methods to analyze multiracial categories, and a small sample size of other Hispanics; transsexual or transgender (n = 4) individuals due to small sample sizes; missing residential census block group (n = 20), missing treatment facility (n = 68), or requiring a ferry for transit/driving time incalculable (n = 3), which were required to determine travel times; driving distance >250 miles (n = 66), which were outliers for travel times. After applying these exclusions, the final study population comprised 22,821 patients.

Assessment of GCT
The primary outcome was receipt of GCT according to the 2016 National Comprehensive Cancer Network (NCCN) guidelines defined as the administration of proper initial and adjuvant surgery, chemotherapy, or radiation treatment(s) according to cancer site and stage. If a patient did not receive surgery, they were assumed inoperable and assessed for GCT according to lymph node staging (N0 or N1). Alternatively, undertreatment was less than minimum site- and stage-specific recommended treatment.

The secondary outcome was receipt of timely (versus delayed) GCT. The Research AND Development Corporation recommends treatment initiation within 6 weeks of diagnosis [54] (i.e., the initiation of surgery, radiation, or chemotherapy within 45 days of diagnosis), and The Commission of Cancer Quality of Care Measures recommends adjuvant treatment of chemotherapy administration within 6 months of surgery, when required [55] (i.e., the initiation of chemotherapy +/- radiation within 6 months of initial surgery for N1 patients); Fig 1.

To determine receipt of GCT and timely treatment, full dates for diagnosis, surgery, radiation, and chemotherapy are required. If only month and year were available, the middle of the month day was imputed.

Assessment of travel time
Mean-centered travel time [56, 57] to treatment facilities including driving and public transit travel times (minutes) to a patient’s chosen treatment facility from their residence was calculated from the centroid of their census block group [58]. ArcGIS Online’s Connect Origins to Destinations Analysis was used to compute driving travel time based on historical and live traffic data [59]. Public transportation was calculable for 11,607 patients living in census blocks with transit service available (nearest transit stop within 0.75 miles). The Google Maps Application Programming Interface with the gmapsdistance function in R was used to compute public transit travel time; gmapsdistance requires a future travel time and was specified as an arrival date and time of Monday, October 9th, 2020 at 5pm; 5pm was chosen to account for less traffic during the COVID-19 pandemic. Driving time was also calculated using gmapsdistance with the same specifications to compare the two methods of calculating driving travel time.

Effect modifiers
Patient race/ethnicity and nSES were investigated as potential effect modifiers of the association between travel time and receipt of GCT. Race/ethnicity was classified as non-Hispanic
White (NHW), non-Hispanic Black (NHB), Hispanic (including those who identify as white or Black), Native Hawaiian and Pacific Islander (NHPI), Chinese, Japanese, Filipino, Korean, Vietnamese, Asian Indian, Other Asian, or American Indian. Race/ethnicity data in the CCR is based on hospital records that use self-report, assumptions of hospital personnel, or extrapolation from birthplace, race/ethnicity of parent, maiden name, or surname [60]. nSES in the CCR is determined from the American Community Survey using a composite residential neighborhood-level index that combines census measures of education, income, occupation, and cost of living at the census block group level and categorized into quintiles [61].

**Covariates**

Covariates included stage at diagnosis [IA (T1ab,N0), IB (T2a,N0), II, NOS (T2,N1), IIA (T2b, N0; T1ab,N1; T2a,N1), IIB (T2b,N1; T3,N0)], year of diagnosis, sex, age, insurance type (not insured, private insurance, Medicaid, Medicare, military, other/not otherwise specified),
marital status (single/never married, partnered (married/unmarried or domestic partner), unpartnered (separated/divorced, widowed)), whether or not the reporting facility with the earliest date of admission had an ACOS-approved cancer program, and rural-urban continuum codes. Rural-urban continuum codes (1–9) distinguishes metropolitan counties by the population of their metro area, and nonmetropolitan counties by degree of urbanization and adjacency to a metro area are assigned to each county [62]. To resolve unavailability of payer (n = 298), marital status (n = 564), and cancer program (n = 46) information, we used multiple imputation, a valid statistical procedure for recovering missing data to create complete datasets that can then be analyzed through standard procedures [63].

**Statistical analysis**

Exposure, clinical and sociodemographic information were stratified by race/ethnicity. We quantified average disproportionality in receipt of GCT and timely treatment across categories of race/ethnicity, nSES, and driving and public transit travel times (<15, 15–30, 30–60, and ≥60 minutes) using three disproportionality functions: Between-Groups Variance (BGV), The Theil Index (T), and Mean Log Deviation (MLD). BGV is a useful metric of absolute disparity for unordered groups, such as race/ethnicity, because it weights by population size and is sensitive to larger deviations from the population average. T and MLD are entropy-based measures that quantify the relative disparity, meaning the disproportionate receipt of GCT and timely GCT across effect modifiers and exposures. T and MLD are complementary measures because T can be influenced by groups with high ratios of GCT and timely GCT in a group relative to the average GCT and timely GCT in the population, and MLD can be influenced by groups with larger population shares [64]; formulas provided in Fig 2.

We used multivariable generalized logistic regression models (PROC GENMOD) with a Poisson distribution and log link function to explore all combinations of the following associations: outcomes (undertreatment and delayed GCT), exposures (mean-centered driving and public transit travel time), and effect modifiers (race/ethnicity and nSES), to estimate the impact of travel time to treatment facilities on both racial/ethnic and socioeconomic disparities

$$\text{BGV} = \sum_{j=1}^{J} p_j (y_j - \mu)^2$$

Where $p_j$ is groups $j$’s population size, $y_j$ is group $j$’s average health status, and $\mu$ is the average health status of the population.

$$T = \sum_{j=1}^{J} p_j r_j \ln(r_j)$$

$$\text{MLD} = \sum_{j=1}^{J} p_j [-\ln(r_j)]$$

Where $p_j$ is the proportion of the population in group $j$ and $r_j$ is the ratio of the mean health status in group $j$ relative to the mean health status in the population.

Fig 2. **Absolute and relative disparities measure formulas.** Average disproportionality in receipt of GCT and timely treatment is measured using three disproportionality functions: Between-Groups Variance (BGV), The Theil Index (T), and Mean Log Deviation (MLD). BGV is a useful metric of absolute disparity for unordered groups. T and MLD are entropy-based measures that quantify the relative disparity. T and MLD are complementary measures.

https://doi.org/10.1371/journal.pone.0272076.g002
in undertreatment and delayed GCT. The intraclass correlation coefficient (ICC) of treatment hospital was assessed to determine if treatment hospital needed to be included as a random effect. Driving and public transit travel times were mean-centered and scaled to represent a 15-minute increase from the population average. Patient racial/ethnic groups with less than 100 persons (NHPI, Asian Indian, and American Indian) were excluded from models due to small sample sizes. In addition to disaggregating Asian groups with sufficient sample sizes, an aggregated Asian American, Native Hawaiian, and Pacific Islander (AANHPI) models was run separately including NHPIs and Asian Indians. Overall, we had 28 covariate-adjusted models. Models 1, 8, 15, and 22 regressed the outcomes (undertreatment and delayed GCT) on the effect modifiers (race/ethnicity and nSES). Models 2, 5, 9, 12, 16, 23, and 26 regressed the outcomes (undertreatment and delayed GCT) on the exposures (driving and public transit time). Models 3, 6, 10, 13, 17, 20, 24, and 27 combined the above models. Models 4, 7, 11, 14, 18, 21, 25, and 28 extended the previous models by adding an interaction term between the effect modifiers (race/ethnicity and nSES), and the exposures (driving and public transit time). The interaction models were the primary models of interest. nSES was not adjusted for when considering race/ethnicity as an effect modifier, but race/ethnicity was adjusted for when considering nSES as an effect modifier. Risk Ratios (RR) and 95% Confidence Intervals (CI) for the effect measure modifier analyses are presented in Table 4, while the betas and 95% CIs for all 28 models are available in (S1 Table, effect modifier: race/ethnicity; S2 Table, effect modifier: nSES). A sensitivity analysis considering driving time calculated using the gmapsdistance function were compared to the above results. All analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC).

Results
Among the 22,821 early-stage NSCLC patients, 18,471 (80.94%) received GCT and, of these, 10,632 (57.56%) received timely GCT. Exposure, clinical and sociodemographic characteristics, stratified by race/ethnicity, are displayed in Table 1. Cells counts <5 are suppressed.

Clinical and sociodemographic characteristics
Stage at diagnosis varied by race/ethnicity with NHBs having the highest proportion of Stage IIB diagnosis (14.9%). Females accounted for 54.5% of patients overall, but 64.4% of Japanese and 40.6% Vietnamese patients. The mean age at diagnosis was 70.4 years overall and ranged from 67.1 years for NHPI to 74.2 years for Japanese patients. Less than 1% of patients were uninsured, and half were married or in a domestic partnership. Most patients were treated at hospitals with an ACOS-approved cancer program (60.5%) with lower rates among NHBs (51.3%), NHPIs (51.5%), and Chinese (52.3%). nSES differed by race/ethnicity; overall, 14.2% of patients lived in the lowest nSES, but NHBs (29.7%), Hispanics (26.5%), and NHPIs (19.7%) proportions were much higher, and most patients lived in metro areas.

Travel time
The mean (μ) driving time was 26 (standard deviation(σ) = 26.5) minutes with NHWs (μ = 26.8), Koreans (μ = 27.1), Asian Indians (μ = 29.4), and American Indians (μ = 26.9) having longer driving times than the average. Half (49.1%) of the population had no public transportation available with unavailability more frequent among NHWs (53.5%), Asian Indians (56.0%), and American Indians (56.3%). Among patients with available public transportation, the mean public transit time was 68.6 (σ = 66.2) minutes with NHWs (μ = 71.3), Koreans (μ = 76.5), and Asian Indians (μ = 96.4) having longer than the average public transit times. Driving
| Exposure Variables | Patient Race/Ethnicity | n (%) or Mean (SD) |
|--------------------|----------------------|------------------|
|                    | All                  | non-Hispanic White (n = 16450) | non-Hispanic Black (n = 1463) | Hispanic (n = 2263) | NHPI (n = 771) | Chinese (n = 180) | Japanese (n = 632) | Korean (n = 195) | Vietnamese (n = 360) | Asian (n = 84) | Other Asian (n = 325) | American Indian (n = 32) |
| Driving Travel Times |                     | 26.0 (26.5) | 26.8 (26.0) | 23.2 (20.7) | 25.1 (24.6) | 25.1 (25.4) | 23.0 (18.9) | 20.9 (14.5) | 23.9 (22.7) | 27.1 (23.3) | 21.6 (15.0) | 29.4 (29.2) | 22.1 (19.5) | 26.9 (25.3) |
< 15 minutes | 8703 (38.1) | 6296 (38.3) | 570 (39.0) | 871 (38.5) | 26 (39.4) | 285 (37.0) | 67 (37.2) | 240 (38.0) | 65 (33.3) | 118 (32.8) | 28 (33.3) | 127 (39.1) | 10 (31.3) |
15–30 minutes | 8345 (36.6) | 5843 (35.5) | 578 (39.5) | 838 (37.0) | 27 (40.9) | 301 (39.0) | 85 (47.2) | 250 (39.6) | 64 (32.8) | 186 (51.7) | 28 (33.3) | 131 (40.3) | 14 (43.8) |
30–60 minutes | 4033 (17.7) | 2896 (17.6) | 252 (17.2) | 409 (18.1) | 8 (12.1) | 158 (20.5) | 23 (12.8) | 110 (17.4) | 47 (24.1) | 46 (12.8) | 21 (25.0) | 57 (17.5) | 6 (18.8) |
≥ 60 minutes | 1740 (7.6) | 1415 (8.6) | 63 (4.3) | 145 (6.4) | 5 (2.8) | 32 (5.1) | 19 (9.7) | 10 (2.8) | 7 (8.3) | 10 (3.1) | -- | -- | -- |
| Public Transit Travel Times | | 68.6 (66.2) | 71.3 (70.6) | 60.5 (45.7) | 67.2 (68.3) | 64.6 (50.8) | 54.7 (49.9) | 61.2 (34.7) | 65.4 (49.9) | 76.5 (89.9) | 62.4 (39.1) | 96.4 (90.4) | 61.8 (34.3) | 64.6 (32.5) |
< 15 minutes | 476 (2.1) | 302 (1.8) | 48 (3.3) | 47 (2.1) | -- | 37 (4.8) | -- | 18 (2.9) | 5 (2.6) | 6 (1.7) | -- | 6 (1.9) | -- |
15–30 minutes | 1891 (8.3) | 1241 (7.5) | 183 (12.5) | 191 (8.4) | 10 (15.2) | 114 (14.8) | 15 (8.3) | 42 (6.7) | 24 (12.3) | 39 (10.8) | -- | 29 (8.9) | -- |
30–60 minutes | 4186 (18.3) | 2692 (16.4) | 417 (28.5) | 473 (20.9) | 14 (21.2) | 197 (25.6) | 42 (23.3) | 133 (21.0) | 43 (22.1) | 95 (26.4) | 12 (14.3) | 67 (20.6) | -- |
≥ 60 minutes | 5054 (22.2) | 3411 (20.7) | 452 (30.9) | 508 (22.5) | 15 (22.7) | 179 (23.2) | 43 (23.9) | 169 (26.7) | 65 (33.3) | 97 (26.9) | 22 (26.2) | 83 (25.5) | 10 (31.3) |
Unavailable | 11214 (49.1) | 8804 (53.5) | 363 (24.8) | 1044 (46.1) | 27 (40.9) | 244 (31.7) | 76 (42.2) | 270 (42.7) | 58 (29.7) | 123 (34.2) | 47 (56.0) | 140 (43.1) | 18 (56.3) |

**Clinical and Sociodemographic Characteristics**

| Stage | n (%) or Mean (SD) |
|-------|------------------|
| IA | 10522 (46.1) | 7720 (46.9) | 619 (42.3) | 1008 (44.5) | 30 (45.5) | 333 (43.2) | 74 (41.1) | 277 (43.8) | 78 (40.0) | 172 (47.8) | 31 (36.9) | 164 (50.5) | 16 (30.0) |
| IB | 7259 (31.8) | 5182 (31.5) | 452 (30.9) | 738 (32.6) | 20 (30.3) | 263 (34.1) | 65 (36.1) | 218 (34.5) | 70 (35.9) | 113 (31.4) | 38 (45.2) | 89 (27.4) | 11 (34.4) |
| II | 35 (0.2) | 21 (0.1) | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| IIA | 2458 (10.8) | 1718 (10.4) | 171 (11.7) | 251 (11.1) | 7 (10.6) | 101 (13.1) | 19 (10.6) | 76 (12.0) | 28 (14.4) | 35 (9.7) | 8 (9.5) | 41 (12.6) | -- |
| IIB | 2547 (11.2) | 1809 (11.0) | 218 (14.9) | 262 (11.6) | 9 (13.6) | 71 (9.2) | 22 (12.2) | 58 (9.2) | 19 (9.7) | 40 (11.1) | 7 (8.3) | 30 (9.2) | -- |
| Year of diagnosis | 2010.7 (2.9) | 2010.6 (2.9) | 2010.8 (2.8) | 2010.9 (2.8) | 2011.4 (2.9) | 2010.9 (2.9) | 2010.1 (2.8) | 2011.0 (2.8) | 2011.0 (2.7) | 2011.0 (2.9) | 2011.2 (2.7) | 2011.7 (2.7) |
| 2006–2010 | 10760 (47.2) | 8003 (48.7) | 50 (3.4) | 990 (43.8) | 27 (40.9) | 333 (43.2) | 98 (54.4) | 266 (42.1) | 87 (44.6) | 145 (40.3) | 34 (40.5) | 100 (30.8) | 13 (40.6) |

(Continued)
|          | All               | non-Hispanic White (n = 16450) | non-Hispanic Black (n = 1463) | Hispanic (n = 2263) | NHPI (n = 771) | Chinese (n = 180) | Japanese (n = 632) | Korean (n = 195) | Vietnamese (n = 360) | Asian Indian (n = 84) | Other Asian (n = 325) | American Indian (n = 32) |
|----------|-------------------|-------------------------------|-------------------------------|-------------------|-------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| **2011–2015** | 12061 (52.9) | 8447 (51.4)                  | 451 (30.8)                   | 1273 (56.3)      | 39 (59.1) | 438 (56.8)     | 82 (45.6)      | 366 (57.9) | 108 (55.4) | 215 (59.7) | 50 (59.5) | 225 (69.2) | 19 (59.4) |
| **Sex**  |                   |                               |                               |                   |       |                 |               |              |              |              |              |              |              |
| Male     | 10383 (45.5)      | 7390 (44.9)                  | 645 (44.1)                   | 978 (43.2)       | 32 (48.5) | 415 (53.8)     | 64 (35.6)      | 316 (50.0) | 113 (58.0) | 214 (59.4) | 46 (54.8) | 154 (47.4) | 16 (50.0) |
| Female   | 12438 (54.5)      | 9060 (55.1)                  | 818 (55.9)                   | 1285 (56.8)      | 34 (51.5) | 356 (46.2)     | 116 (64.4)     | 316 (50.0) | 82 (42.1)  | 146 (40.6) | 38 (45.2) | 171 (52.6) | 16 (50.0) |
| **Age groups** |                |                               |                               |                   |       |                 |               |              |              |              |              |              |              |
| 18 through 45 | 394 (1.7)       | 200 (1.2)                    | 329 (22.5)                   | 95 (4.2)         | --     | 16 (2.1)       | --             | 10 (1.6)   | 5 (2.6)    | 11 (3.1)   | 9 (10.7)  | 14 (4.3)    | --             |
| 46 through 60 | 3453 (15.1)     | 2284 (13.9)                  | (0.0)                        | 381 (16.8)       | 18 (27.3) | 126 (16.3)     | 18 (10.0)      | 100 (15.8) | 29 (14.9)  | 78 (21.7)  | 12 (14.3) | 60 (18.5)   | 10 (31.3)     |
| 61 through 75 | 11169 (48.9)   | 8100 (49.2)                  | 664 (45.4)                   | 1042 (46.1)      | 32 (48.5) | 352 (45.7)     | 67 (37.2)      | 323 (51.1) | 108 (55.4) | 178 (49.4) | 43 (51.2) | 148 (45.5)  | 10 (31.3)     |
| 76 +     | 7805 (34.2)      | 5866 (35.7)                  | 799 (54.6)                   | 745 (32.9)       | 15 (22.7) | 277 (35.9)     | 94 (52.2)      | 199 (31.5) | 53 (27.2)  | 93 (25.8)  | 20 (23.8) | 103 (31.7)  | 11 (34.4)     |
| **Payer** |                   |                               |                               |                   |       |                 |               |              |              |              |              |              |              |
| Not insured | 155 (0.7)       | 85 (0.5)                      | 14 (1.0)                     | 31 (1.4)         | --     | --             | --             | 6 (1.0)    | 5 (2.6)    | --             | --             | 7 (2.2)     | --             |
| Private   | 8493 (37.2)      | 6064 (36.9)                  | 568 (38.8)                   | 818 (36.2)       | 21 (31.8) | 339 (44.0)     | 77 (42.8)      | 270 (42.7) | 54 (27.7)  | 101 (28.1) | 31 (36.9) | 137 (42.2)  | 13 (40.6)     |
| Medicaid  | 1097 (4.8)       | 543 (3.3)                     | 165 (11.3)                   | 188 (8.3)        | 7 (10.6) | 51 (6.6)       | --             | 58 (9.2)   | 13 (6.7)   | 34 (9.4)   | 9 (10.7)  | 28 (8.6)    | --             |
| Medicare  | 11946 (52.4)     | 8962 (54.5)                   | 632 (43.2)                   | 1115 (49.3)      | 34 (51.5) | 324 (42.0)     | 97 (53.9)      | 275 (43.5) | 116 (59.5) | 198 (55.0) | 36 (42.9) | 143 (44.0)  | 14 (43.8)     |
| Military  | 104 (0.5)        | 81 (0.5)                      | 8 (0.6)                      | 8 (0.4)          | --     | --             | --             | --         | --         | --         | --         | --           | --             |
| Other or NOS | 728 (3.2)    | 492 (3.0)                     | 55 (3.7)                     | 76 (3.3)         | --     | 45 (5.8)       | 5 (2.8)        | 13 (2.1)   | 5 (2.6)    | 22 (6.1)   | --         | 8 (2.5)     | --             |
| Missing   | 298 (1.3)        | 223 (1.4)                     | 21 (1.4)                     | 27 (1.2)         | --     | --             | --             | 7 (1.1)    | --         | --         | --         | --           | --             |
| **Marital Status at diagnosis** |             |                               |                               |                   |       |                 |               |              |              |              |              |              |              |
| Single    | 564 (2.5)        | 2097 (12.8)                   | 451 (30.38)                  | 321 (14.2)       | 9 (13.6) | 48 (6.2)       | 16 (8.9)       | 37 (5.9)   | 12 (6.2)   | 35 (9.7)   | 6 (7.1)   | 31 (9.5)    | 5 (15.6)     |
| Partnered | 12091 (53.0)     | 8567 (52.1)                   | 504 (34.5)                   | 1181 (52.2)      | 39 (59.1) | 574 (74.5)     | 112 (62.2)     | 429 (67.9) | 142 (72.8) | 261 (72.5) | 67 (79.8) | 201 (61.9)  | 14 (43.8)     |
| Unpartnered | 3068 (13.4)    | 5391 (32.8)                   | 458 (31.3)                   | 698 (30.8)       | 16 (24.2) | 134 (17.4)     | 51 (28.3)      | 154 (24.4) | 35 (18.0)  | 55 (15.3)  | 11 (13.1) | 84 (25.9)   | 11 (34.4)     |

(Continued)
| Patient Race/Ethnicity | All (n = 16450) | non-Hispanic White (n = 14630) | Hispanic (n = 2263) | NHPI (n = 771) | Chinese (n = 180) | Japanese (n = 632) | Korean (n = 195) | Vietnamese (n = 360) | Asian Indian (n = 84) | Other Asian (n = 325) | American Indian (n = 32) |
|------------------------|----------------|-----------------------------|------------------|---------------|-----------------|-------------------|-----------------|-------------------|---------------------|---------------------|---------------------|
| Missing                | 7098 (40.1)   | 395 (2.4)                   | 50 (3.4)         | 63 (2.8)      | --              | 15 (2.0)          | --              | 12 (1.9)          | 6 (3.1)             | 9 (2.5)             | 6 (7.1)             | 9 (2.8)             |
| Cancer Program         |                |                             |                  |               |                 |                   |                 |                   |                    |                    |                    |                    |
| Approved               | 13803 (60.5)  | 10179 (61.9)                | 751 (51.3)       | 1313 (58.0)   | 34 (51.5)       | 403 (52.3)        | 108 (60.0)      | 351 (55.5)       | 126 (64.6)          | 264 (73.3)          | 59 (70.2)           | 197 (60.6)          |
| Not approved           | 8972 (39.3)   | 6240 (37.9)                 | 709 (48.5)       | 948 (41.9)    | 31 (47.0)       | 366 (47.5)        | 70 (38.9)       | 278 (44.0)       | 68 (34.9)           | 95 (26.4)           | 25 (29.8)           | 128 (39.4)          |
| Missing                | 46 (0.2)      | 31 (0.2)                    | --              | --            | --              | --                | --              | --                | --                  | --                  | --                  |
| Neighborhood Social Economic Status |            |                             |                  |               |                 |                   |                 |                   |                    |                    |                    |
| lowest                 | 3243 (14.2)   | 1889 (11.5)                 | 435 (29.7)       | 600 (26.5)    | 13 (19.7)       | 103 (13.4)        | 11 (6.1)        | 79 (12.5)        | 25 (12.8)           | 41 (11.4)           | --                  | 41 (12.6)           |
| lower-middle           | 4494 (19.7)   | 3041 (18.5)                 | 389 (26.6)       | 558 (24.7)    | 17 (25.8)       | 89 (11.5)         | 34 (18.9)       | 122 (19.3)       | 39 (20.0)           | 109 (30.3)          | 10 (11.9)           | 73 (22.5)           | 13 (40.6)          |
| middle                 | 4927 (21.6)   | 3568 (21.7)                 | 309 (21.1)       | 508 (22.5)    | 14 (21.2)       | 130 (16.9)        | 41 (22.8)       | 161 (25.5)       | 35 (18.0)           | 84 (23.3)           | 14 (16.7)           | 57 (17.5)           | 6 (18.8)           |
| upper-middle           | 5025 (22.0)   | 3845 (23.4)                 | 214 (14.6)       | 363 (16.0)    | 12 (18.2)       | 186 (24.1)        | 46 (25.6)       | 162 (25.6)       | 37 (19.0)           | 67 (18.6)           | 20 (23.8)           | 66 (20.3)           | 7 (21.9)           |
| highest                | 5132 (22.5)   | 4107 (25.0)                 | 116 (7.9)        | 234 (10.3)    | 10 (15.2)       | 263 (34.1)        | 48 (26.7)       | 108 (17.1)       | 59 (30.3)           | 59 (16.4)           | 38 (45.2)           | 88 (27.1)           | --                |
| Rural-Urban Continuum Code |            | 1.4 (0.9)                  | 1.5 (1.0)        | 1.1 (0.4)     | 1.3 (0.7)       | 1.3 (0.7)         | 1.0 (0.2)       | 1.2 (0.5)        | 1.2 (0.4)           | 1.1 (0.3)           | 1.0 (0.2)           | 1.3 (0.5)           | 1.1 (0.4)           | 1.9 (1.4)          |
| 1: Metro (1 million or more) | 17007 (74.5) | 16579 (70.9)                | 1283 (87.7)      | 1688 (74.6)   | 49 (74.2)       | 743 (96.4)        | 150 (83.3)      | 540 (85.4)       | 185 (94.9)          | 349 (96.9)          | 66 (78.6)           | 279 (85.9)          | 18 (56.3)          |
| 2: Metro (250,000 to 1 million) | 4133 (18.1) | 3241 (19.9)                 | 163 (11.1)       | 466 (20.6)    | 13 (19.7)       | 25 (3.2)          | 29 (16.1)       | 81 (12.8)        | 9 (4.6)             | 10 (2.8)            | 15 (17.9)           | 44 (13.5)           | 7 (21.9)           |
| 3: Metro (fewer than 250,000 population) | 910 (4.0) | 789 (4.8)                   | 15 (1.0)         | 80 (3.5)      | --              | --                | --              | 10 (1.6)         | --                  | --                  | --                  | --                  | --                |
| 4: Nonmetro (20,000 or more, adjacent to a metro area) | 426 (1.9) | 406 (2.5)                   | --              | 18 (0.8)      | --              | --                | --              | --                | --                  | --                  | --                  | --                  | --                |
| 5: Nonmetro (20,000 or more, not adjacent to a metro area) | 105 (0.5) | 101 (0.6)                   | --              | --            | --              | --                | --              | --                | --                  | --                  | --                  | --                  | --                |
| 6: Nonmetro (2,500 to 19,999, adjacent to a metro area) | 166 (0.7) | 155 (0.9)                   | --              | 8 (0.4)       | --              | --                | --              | --                | --                  | --                  | --                  | --                  | --                |
| 7: Nonmetro (2,500 to 19,999, not adjacent to a metro area) | 41 (0.2) | 40 (0.2)                    | --              | --            | --              | --                | --              | --                | --                  | --                  | --                  | --                  | --                |

(Continued)
Table 1. (Continued)

| Patient Race/ethnicity | NHPI (n = 66) | American Indian (n = 15) | Other Asian (n = 32) | Asian Indian (n = 84) | Vietnamese (n = 360) | Korean (n = 195) | Filipino (n = 632) | Japanese (n = 180) | Hispanic (n = 2263) | Black (n = 1463) | White (n = 16450) | non-Hispanic (n = 10449) |
|------------------------|--------------|-------------------------|----------------------|----------------------|----------------------|------------------|------------------|------------------|---------------------|-----------------|----------------------|-----------------------------|
| All                    | 73 (0.3%)    | 31 (0.2%)               | -                    | -                    | -                    | -                | -                | -                | -                   | -               | -                    | -                           |

*Cell counts < 5 suppressed.*
and public transit times, stratified by nSES, are provided in (S3 Table). Patients with the highest nSES have the shortest travel times.

**Absolute and relative disparity measures**

The proportions of receipt of GCT ranged from 76.35% among NHBs to 84.70% among Chinese and the proportions of receipt of timely treatment ranged from 49.80% among Filipinos to 72.06% among Other Asians. Patient’s living in the highest nSES had the highest proportion of GCT (84.53%) and timely treatment (66.25%), followed by upper-middle, middle, lower-middle, and lowest SES (GCT = 75.33%; timely GCT = 50.43%) nSES (Table 2). Patients with a ≥60 minutes driving time had the highest percent GCT (86.90%) and timely treatment (64.95%), followed by 30–60, 15–30, and <15 minutes (GCT = 77.36%; timely treatment = 56.29%). Patients with a ≥60 minutes public transit time had the highest proportion of GCT (82.33%) and timely GCT (58.65%) (Table 3). BVG, Theil, and MLD values range from 0 to ∞ (higher inequality) and should be used to compare the level of inequality across outcomes and groups. We observed more absolute disparity in rate of timely GCT, compared to GCT, between race/ethnicity (GCT = 3.65; timely GCT = 8.65) and nSES (GCT = 10.10; timely GCT = 28.35), with higher absolute disparity in nSES compared to race/ethnicity. There was more absolute disparity in GCT (driving = 10.73; public transit = 8.60) compared to timely GCT (driving = 5.65; public transit = 2.18), between travel times. There was very little relative disparity in rate of GCT and timely GCT.

To explain how driving and public transit time impacted the risk of undertreatment and delayed GCT, multivariable mean-centered models are described below. Treatment hospital had an intraclass correlation coefficient of <5% and therefore was not included as a random effect.

**Outcomes and effect modifiers.** Compared to NHWs, NHBs (β = 0.21, 95% CI = 0.11–0.30), Hispanics (β = 0.20, 95%CI = 0.12–0.28), and Vietnamese (β = 0.34, 95% CI = 0.15–0.54) had higher risks for undertreatment, and NHWs (β = 0.15, 95%CI = 0.09–0.22), Hispanics (β = 0.08, 95%CI = 0.03–0.14), and Filipinos (β = 0.18, 95%CI = 0.10–0.27) had higher risk for delayed GCT (S1 Table). Compared to patients in the highest nSES, patients in the middle (β = 0.13, 95% CI = 0.05–0.21), lower-middle (β = 0.23, 95%CI = 0.15–0.31), and lowest (β = 0.30, 95% CI = 0.22–0.39) nSES had higher risk for undertreatment, and those in the upper-middle (β = 0.19, 95% CI = 0.14–0.25), middle (β = 0.24, 95% CI = 0.18–0.29), lower-middle (β = 0.27, 95% CI = 0.22–0.33), and lowest (β = 0.32, 95%CI = 0.26–0.38) nSES had higher risk for delayed GCT (S2 Table).

**Outcomes and exposures.** When considering all patients, a 15-minute increase (from the mean) in driving time was associated with a 5.48% (β = -0.06, 95%CI = -0.08,-0.04) and 3.10% (β = -0.03, 95%CI = -0.04,-0.02) decreased relative risk for undertreatment and delayed treatment, respectively, and a 15-minute increase in public transit times was associated with a 1.78% (β = -0.02, 95% CI = -0.03,-0.01) and 0.7% (β = -0.01, 95% CI = -0.01,0.00) decreased relative risk for undertreatment and delayed GCT, respectively (S2 Table). However, increased travel times did not translate to improved care for all racial/ethnic or socioeconomic groups as evidenced by our joint exposure models.

**Outcomes, effect modifiers, exposures, and interactions.** Considering a joint exposure that incorporates both travel time and race/ethnicity, a 15-minute increase in driving time for NHBs and Koreans increased their risk of undertreatment by 24% (95%CI = 8%-42%) and 37% (95%CI = 2%-82%), respectively, compared to NHWs. A 15-minutes increase in public transit time for NHBs, Hispanics, Vietnamese, and Other Asians increased their risk of undertreatment by 29% (95%CI = 14%-46%), 32% (95%CI = 16%-49%), 49% (95%CI = 15%-93%), respectively.
## Table 2. Absolute and relative disparities in rate of GCT and Timely GCT between patient race/ethnicity groups and neighborhood socioeconomic status (nSES).

| Patient Race/Ethnicity | GCT (%) | Proportion of Population | BVG | Theil | MLD |
|------------------------|---------|--------------------------|-----|-------|-----|
| NHW (n = 16450)        | 81.75   | 0.7208                   | 0.4729 | 0.0072 | -0.0072 |
| NHB (n = 1463)         | 76.35   | 0.0641                   | 1.3505 | -0.0035 | 0.0037 |
| Hispanic (n = 2263)    | 77.60   | 0.0992                   | 1.1066 | -0.0040 | 0.0042 |
| NHPI (n = 66)          | 78.79   | 0.0029                   | 0.0134 | -0.0001 | 0.0001 |
| Chinese (n = 771)      | 84.70   | 0.0338                   | 0.4779 | 0.0016 | -0.0015 |
| Japanese (n = 180)     | 82.78   | 0.0079                   | 0.0267 | 0.0002 | -0.0002 |
| Filipino (n = 632)     | 80.70   | 0.0277                   | 0.0016 | -0.0001 | 0.0001 |
| Korean (n = 195)       | 78.46   | 0.0085                   | 0.0523 | -0.0003 | 0.0003 |
| Vietnamese (n = 360)   | 78.61   | 0.0158                   | 0.0858 | -0.0004 | 0.0004 |
| Asian Indian (n = 84)  | 80.95   | 0.0037                   | 0.0000 | 0.0000 | 0.0000 |
| Other Asian (n = 325)  | 78.77   | 0.0142                   | 0.0669 | -0.0004 | 0.0004 |
| American Indian (n = 32)| 81.25   | 0.0014                   | 0.0001 | 0.0000 | 0.0000 |
| All Groups             | 80.94   | 3.6547                   | 0.0003 | 0.0003 | 0.0003 |

| Patient Race/Ethnicity | Timely GCT (%) | Proportion of Population | BVG | Theil | MLD |
|------------------------|----------------|--------------------------|-----|-------|-----|
| NHW (n = 13448)        | 58.43          | 0.7281                   | 0.5511 | 0.0111 | -0.0109 |
| NHB (n = 1117)         | 50.04          | 0.0605                   | 3.4213 | -0.0074 | 0.0085 |
| Hispanic (n = 1756)    | 54.78          | 0.0951                   | 0.7350 | -0.0045 | 0.0047 |
| NHPI (n = 52)          | 65.38          | 0.0028                   | 0.1712 | 0.0004 | -0.0004 |
| Chinese (n = 653)      | 60.34          | 0.0354                   | 0.2736 | 0.0018 | -0.0017 |
| Japanese (n = 149)     | 57.72          | 0.0081                   | 0.0000 | 0.0000 | 0.0000 |
| Filipino (n = 510)     | 49.80          | 0.0276                   | 1.6620 | -0.0035 | 0.0040 |
| Korean (n = 153)       | 61.44          | 0.0083                   | 0.1250 | 0.0006 | -0.0005 |
| Vietnamese (n = 283)   | 56.89          | 0.0153                   | 0.0069 | -0.0002 | 0.0002 |
| Asian Indian (n = 68)  | 72.06          | 0.0037                   | 0.7779 | 0.0010 | -0.0008 |
| Other Asian (n = 256)  | 65.63          | 0.0139                   | 0.9052 | 0.0021 | -0.0018 |
| American Indian (n = 26)| 53.85          | 0.0014                   | 0.0001 | -0.0001 | 0.0001 |
| All Groups             | 57.56          | 8.6486                   | 0.0014 | 0.0013 | 0.0013 |

| nSES                    | GCT (%) | Proportion of Population | BVG | Theil | MLD |
|-------------------------|---------|--------------------------|-----|-------|-----|
| Highest (n = 5132)      | 84.53   | 0.2249                   | 2.8985 | 0.0102 | -0.0098 |
| Upper-Middle (n = 5025) | 83.24   | 0.2202                   | 1.1649 | 0.0063 | -0.0062 |
| Middle (n = 4927)       | 81.10   | 0.2159                   | 0.0055 | 0.0004 | -0.0004 |
| Lower-Middle (n = 4494) | 78.13   | 0.1969                   | 1.5547 | -0.0067 | 0.0070 |
| Lowest (n = 3243)       | 75.33   | 0.1421                   | 4.4722 | -0.0095 | 0.0102 |
| All Groups              | 80.94   | 10.0958                  | 0.0008 | 0.0008 | 0.0008 |

| nSES                    | Timely GCT (%) | Proportion of Population | BVG | Theil | MLD |
|-------------------------|----------------|--------------------------|-----|-------|-----|
| Highest (n = 4338)      | 66.25          | 0.2349                   | 17.7387 | 0.0380 | -0.0330 |
| Upper-Middle (n = 4183) | 57.95          | 0.2265                   | 0.0345 | 0.0015 | -0.0015 |
| Middle (n = 3996)       | 55.56          | 0.2163                   | 0.8652 | -0.0074 | 0.0076 |
| Lower-Middle (n = 3511) | 53.60          | 0.1901                   | 2.9811 | -0.0126 | 0.0136 |
| Lowest (n = 2443)       | 50.43          | 0.1323                   | 6.7257 | -0.0153 | 0.0175 |
| All Groups              | 57.56          | 28.3452                  | 0.0042 | 0.0041 | 0.0041 |

https://doi.org/10.1371/journal.pone.0272076.t002
and 39% (95%CI = 7%-82%) respectively, compared to NHWs. A 15-minute increase in driving time for NHBs and Filipinos increased their risk of delayed GCT by 17% (95%CI = 7%-28%) and 27% (95%CI = 15%-41%), respectively, compared to NHWs. A 15-minutes increase in public transit time for NHBs, Hispanics, and Filipinos increased their risk of delayed GCT by 18% (95%CI = 9%-28%), 12% (95%CI = 4%-21%), and 27% (95%CI = 13%-42%), respectively, compared to NHWs (Table 4).

Considering a joint exposure that incorporates both travel time and nSES, a 15-minute increase in driving time for patients in the lower-middle and lowest nSES increased their risk of undertreatment by 27% (95%CI = 12%-44%) and 33% (95%CI = 16%-52%) compared to patients in the highest nSES (P-for-trend<0.01), respectively. A 15-minute increase in public transit time for patients in the lower-middle and lowest nSES increased their risk of undertreatment by 31% (95%CI = 16%-49%) and 39% (95%CI = 22%-59%), respectively, compared to patients in the highest nSES (P-for-trend<0.01). A 15-minute increase in driving time for patients in the upper-middle, middle, lower-middle, and lowest nSES increased their risk of delayed GCT by 26% (95%CI = 16%-36%) to 44% (95%CI = 33%-56%) compared to patients in the highest nSES (P-for-trend<0.01). A 15-minute increase in public transit time for patients in the upper-middle, middle, lower-middle, and lowest nSES increased their risk of
### Table 4. Risk Ratios (RR) and 95% Confidence Intervals (CI) for race/ethnicity and neighborhood socioeconomic status (nSES) representing that effect as modified by a 15-minute increase in travel time.

| Effect Modifier | Outcome: Under treatment | Outcome: Delayed GCT |
|-----------------|--------------------------|---------------------|
|                 | Exposure: Driving Time   | Exposure: Public Transit Time |
|                 | Model 4 Summary<sup>a</sup> | Model 18 Summary<sup>a</sup> | Model 7 Summary<sup>b</sup> | Model 25 Summary<sup>b</sup> |
|                 | Reference (RR (95 CI))    | Reference (RR (95 CI))    |
| Race/Ethnicity  |                          |                          |
| NHW             | Reference                 | Reference (1.24 (1.08, 1.42)) |
| NHB             | 1.29 (1.14, 1.46)         | 1.17 (1.07, 1.28)         |
| Hispanic        | 1.32 (1.16, 1.49)         | 1.06 (0.99, 1.14)         |
| AANHPI<sup>c</sup> | 1.10 (0.98, 1.24)         | 1.00 (0.93, 1.08)         |
| Chinese         | 0.85 (0.64, 1.14)         | 0.88 (0.75, 1.03)         |
| Japanese        | 1.15 (0.80, 1.65)         | 1.14 (0.85, 1.54)         |
| Filipino        | 1.06 (0.84, 1.33)         | 1.27 (1.15, 1.44)         |
| Korean          | 1.04 (0.73, 1.48)         | 0.86 (0.62, 1.19)         |
| Vietnamese      | 1.49 (1.15, 1.93)         | 0.96 (0.74, 1.24)         |
| Other Asian     | 1.39 (1.07, 1.82)         | 0.87 (0.70, 1.10)         |
| nSES            |                          |                          |
| Highest         | Reference                 | Reference (1.37 (1.02, 1.82)) |
| Upper-Middle    | 1.06 (0.93, 1.21)         | 1.26 (1.16, 1.36)         |
| Middle          | 1.15 (1.01, 1.30)         | 1.29 (1.20, 1.40)         |
| Lower-Middle    | 1.31 (1.16, 1.49)         | 1.38 (1.28, 1.49)         |
| Lowest          | 1.39 (1.22, 1.59)         | 1.44 (1.33, 1.56)         |
| P trend         | < 0.0001                  | < 0.0001                 |

<sup>a</sup> Separate model with aggregate AANHPI which include NHPI and Asian Indians.

<sup>b</sup> Risk Ratio (Exponentiated Estimate) for Race/Ethnicity represents Race/Ethnicity effect (reference: non-Hispanic white with 15-minute increase in travel time) as modified by a 15-minute increase in travel time (with product term to capture effect modification by travel time), adjusted for age, year of diagnosis, stage at diagnosis, sex, insurance, marital status, cancer approved program, and rural-urban continuum code.

<sup>c</sup> Risk Ratio (Exponentiated Estimates) for nSES represent nSES effects (reference: Highest nSES with 15-minute increase in travel time) as modified by a 15-minute increase in travel time (with product term to capture effect modification by travel time), adjusted for age, year of diagnosis, stage at diagnosis, sex, race/ethnicity, insurance, marital status, cancer approved program, and rural-urban continuum code.

https://doi.org/10.1371/journal.pone.0272076.t004
delayed GCT by 13% (95%CI = 4%-23%) to 27% (95%CI = 16%-39%) compared to patients in the highest nSES (P-for-trend<0.01) (Table 4).

Sensitivity analyses considering driving time calculated using gmapsdistance were compared to the above results using ArcGIS Online’s Connect Origins to Destinations Analysis. Estimates differed slightly, but groups at significantly increased risk for undertreatment and delayed GCT were consistent (S4 Table).

Discussion

Racial/ethnic and socioeconomic disparities in receipt of GCT and timely treatment exist among early-stage NSCLC patients in California. NHBs experienced the lowest rate of GCT and Filipinos and NHBs experienced the lowest rates of timely treatment, and patients living in the highest nSES experienced the highest rate of timely GCT with a linear decreasing trend with decreasing nSES. On average, a 15-minute increase in travel time was associated with a decreased risk for undertreatment and delayed treatment. This protective effect observed from increased travel times was unexpected and may be a “Travel Time Paradox,” but this paradox was not uniform across all groups.

NHBs and Hispanics were at higher relative risk as compared to Whites for undertreatment and delayed treatment. NHBs and Hispanics had shorter travel times and the highest proportions of patients in lower nSES. Interestingly, when considering the interaction between travel time and race/ethnicity, a 15-minute increase in driving time for Hispanics attenuated the risk of undertreatment and delayed treatment, compared to NHWs. This could be explained by healthcare facilities near Hispanic neighborhoods being poorer. Opposing, a 15-minute increase in public transit time for Hispanics increased the magnitude of risk of undertreatment and delayed treatment, compared to NHWs. It is unclear why this “Travel Time Paradox” would not hold in Hispanics for public transit, but it may be that patients requiring public transit are less likely to travel farther for better care when travel times are already three times longer than driving. Further, a 15-minute increase in driving and public transit time for NHBs increased risk of undertreatment and delayed treatment, compared to NHWs. This supports a racial/ethnic disparity that is not overcome by a farther, more qualified, healthcare facility.

In aggregate, AANHPIs were not at increased relative risk for undertreatment or delayed treatment, however, by disaggregated Asian groups important heterogeneity was illuminated. Compared to NHWs, Koreans and Vietnamese were at higher risk for undertreatment and Filipinos were at higher risk for delayed treatment. Filipinos and Vietnamese had shorter travel times and relatively average nSES. For Vietnamese, however, a 15-minute increase in driving time for Vietnamese appears to protect against undertreatment compared to NHWs and reveals the benefit for Vietnamese to travel farther for better cancer care. On the other hand, a 15-minute increase in public transit time for Vietnamese increases the risk of undertreatment, compared to NHWs. A 15-minute increase in driving and public transit time for Filipinos increases the risk of undertreatment and exaggerates the risk of delayed treatment, compared to NHWs. Lastly, Other Asians are at higher risk for undertreatment and lower risk for delayed treatment compared to NHWs, but a 15-minute increase in travel time significantly increases risk for undertreatment and delayed treatment, compared to NHWs.

We observed a linear relationship between increased travel time and risk of undertreatment and treatment delay by decreasing quintile of nSES. For patients in the lowest nSES, a 15-minute increase in travel time resulted in 33–39% and 27–44% increased risks of undertreatment and delayed treatment, respectively. This may be explained by lower socioeconomic patients not having as good of choices, even if traveling farther. Interestingly, a 15-minute increase in driving time for non-highest nSES patients increases the risk of delayed treatment and a
15-minute increase in public transit time for the non-highest nSES patients attenuates the risk of delayed treatment, compared to the highest nSES patients. This may be due to patients in lower nSES wanting to drive farther for better care, but it simply taking longer to find the time. In previous U.S. studies [65–67], increased travel distance within urban areas decreased receipt of timely treatment, while within rural areas, the inverse relationship was found. These studies considered distance as opposed to time, which may have influenced results as driving the same distance in an urban setting likely takes longer than in a rural setting. Our public transit time results generally represent urban areas in which this ‘Travel Time Paradox’ holds, although attenuated compared to driving time, and contradictory to the above studies’ findings. Most other U.S. studies considered assessed travel distance as opposed to travel time, and found that increased travel distance decreased likelihood of treatment [28, 35–37].

This “Travel Time Paradox” has not been previously reported in U.S. patients. In one Australian study, early-stage NSCLC patients living farther away were less likely to have surgery and more likely to attend a general hospital rather than a specialist hospital. But, for patients that were treated in specialist hospitals, the relationship with distance was inverse showing a protective effect with longer distance [21]. Although our study is not directly comparable due to differences in healthcare systems, our study supports the hypothesis that patients may choose, if resources allow, to travel farther for better cancer care, and the closest hospital may not have the resources to provide proper treatment. Further, two recent U.S. studies showed that early-stage NSCLC who were treated at an academic facility compared to a community facility had significantly higher median overall survival, and Black patients were more likely to undergo surgery at academic facilities [68, 69]. Our study controlled for ACOS-approved cancer program to try and account for quality of care and the importance of facility type, but also found no random effect by treatment facility.

We considered a patient’s chosen treatment facility as opposed to the nearest facility, as often examined [14–23, 28, 32, 34, 36, 43, 49, 50, 65–67]. Considering the nearest treatment facility may make sense in countries with universal healthcare or clearly defined catchment regions, but this topic is much more complex in the U.S. where patients’ healthcare utilization is driven by insurance, choice, and convenience [70]. Thus, our observed ‘Travel Time Paradox’ may be driven by a patient’s choice to travel further for improved cancer care.

The findings from this study should be interpreted in light of the limitations. The CCR does not provide patient refusal or comorbidities preventing treatment which could result in outcome misclassification. Further, a patient’s ability to get appropriate care may be attributable to more than just proximity to care. One consideration is that wealthier patients may choose to travel farther for their cancer care than a poorer patient. We tried to unpack this by assessing nSES as an effect modifier, but due to limited sample sizes, we were unable to stratify our results by both race/ethnicity and nSES. A strength of this study includes the presentation of disaggregated Asian groups; aggregating Asians into one group masks heterogeneity between groups. Additionally, we consider a patient’s chosen treatment facility, as opposed to nearest treatment facility, and so our exposure is representative of the treatment facility a patient chose to attend.

These findings help elucidate the cancer-related health disparities within California’s highly diverse population. Undertreatment and delayed treatment for early-stage NSCLC disproportionately affect minorities and those living in lower socioeconomic status neighborhoods. The protective effect observed from increased travel times may be a ‘Travel Time Paradox’. This paradox effect may be partially explained by patients choosing to travel farther for better care or having to travel farther to receive treatment. However, a patient’s ability to travel farther for care could be prohibited for many reasons such as lack of time or personal transportation thus additional healthcare facilities may not be the solution. While cancer treatment transportation
options may be beneficial to patients who lack a private vehicle [71, 72], accessible high-quality healthcare facilities that offer surgery, radiation, and chemotherapy are required.

Supporting information

S1 Table. Effect of travel time to treatment facilities on racial/ethnic disparities in undertreatment and delayed GCT.
(DOCX)

S2 Table. Effect of travel time to treatment facilities on socioeconomic disparities in undertreatment and delayed GCT.
(DOCX)

S3 Table. Driving and public transit times, stratified by neighborhood socioeconomic status.
(DOCX)

S4 Table. Sensitivity analysis: Risk Ratios (RR) and 95% Confidence Intervals (CI) for race/ethnicity and neighborhood socioeconomic status (nSES) representing that effect as modified by a 15-minute increase in driving time calculate using the gmapsdistance function.
(DOCX)

Acknowledgments

The ideas and opinions expressed herein are those of the author(s) and do not necessarily reflect the opinions of the State of California, Department of Public Health, the National Cancer Institute, and the Centers for Disease Control and Prevention or their Contractors and Subcontractors.

Author Contributions

Conceptualization: Chelsea A. Obrochta, James D. Murphy, Atsushi Nara, Caroline A. Thompson.

Data curation: Chelsea A. Obrochta, Atsushi Nara.

Formal analysis: Chelsea A. Obrochta.

Writing – original draft: Chelsea A. Obrochta.

Writing – review & editing: Humberto Parada, Jr., Atsushi Nara, Dennis Trinidad, Maria Rosario (Happy) Araneta, Caroline A. Thompson.

References

1. Nadpara P., Madhavan S.S., and Tworek C., Guideline-concordant Timely Lung Cancer Care and Prognosis among Elderly Patients in the United States: A Population-based Study. Cancer Epidemiol, 2015. 39(6): p. 1136–44. https://doi.org/10.1016/j.canep.2015.06.005 PMID: 26138902

2. Scoggins J.F., et al., Is Distance to Provider a Barrier to Care for Medicaid Patients With Breast, Colorectal, or Lung Cancer? J Rural Health, 2012. 28(1): p. 54–62. https://doi.org/10.1111/j.1748-0361.2011.00371.x PMID: 22236315

3. Stitzenberg K.B., et al., Distance to diagnosing provider as a measure of access for patients with melanoma. Arch Dermatol, 2007. 143(8): p. 991–8. https://doi.org/10.1001/archderm.143.8.991 PMID: 17709657
4. Massarweh N.N., et al., Association between travel distance and metastatic disease at diagnosis among patients with colon cancer. J Clin Oncol, 2014. 32(9): p. 942–9. https://doi.org/10.1200/JCO.2013.52.3845 PMID: 24516014

5. Parsons M.A. and Askland K.D., Cancer of the colorectum in Maine, 1995–1998: determinants of stage at diagnosis in a rural state. J Rural Health, 2007. 23(1): p. 25–32. https://doi.org/10.1111/j.1748-0361.2006.00064.x PMID: 17300475

6. Liff J.M., Chow W.H., and Greenberg R.S., Rural-urban differences in stage at diagnosis. Possible relationship to cancer screening. Cancer, 1991. 67(5): p. 1454–9. https://doi.org/10.1002/1097-0142(19910301)67:5<1454::aid-cncr2820670533>3.0.co;2-k PMID: 1991313

7. Celaya M.O., et al., Breast cancer stage at diagnosis and geographic access to mammography screening (New Hampshire, 1998–2004). Rural Remote Health, 2010. 10(2): p. 1361. PMID: 20438282

8. Huang B., et al., Does distance matter? Distance to mammography facilities and stage at diagnosis of breast cancer in Kentucky. J Rural Health, 2009. 25(4): p. 366–71. https://doi.org/10.1111/j.1748-0361.2009.00245.x PMID: 19780916

9. Wang F., et al., Late-Stage Breast Cancer Diagnosis and Health Care Access in Illinois. Prof Geogr, 2008. 60(1): p. 54–69. https://doi.org/10.1080/00330120701724087 PMID: 18458760

10. Schroen A.T. and Lohr M.E., Travel distance to mammography and the early detection of breast cancer, in Breast J. 2009: United States. p. 216–7.

11. Campbell N.C., et al., Rural and urban differences in stage at diagnosis of colorectal and lung cancers. Br J Cancer, 2001. 84(7): p. 910–4. https://doi.org/10.1054/bjoc.2000.1708 PMID: 11286470

12. Dickens C., et al., Stage at breast cancer diagnosis and distance from diagnostic hospital in a periurban setting: a South African public hospital case series of over 1,000 women. Int J Cancer, 2014. 135(9): p. 2173–82. https://doi.org/10.1002/ijc.28861 PMID: 24658866

13. Satasivam P., et al., The dilemma of distance: patients with kidney cancer from regional Australia present at a more advanced stage. BJU Int, 2014. 113 Suppl 2: p. 57–63.

14. Schroen A.T., et al., Impact of patient distance to radiation therapy on mastectomy use in early-stage breast cancer patients. J Clin Oncol, 2005. 23(28): p. 7074–80. https://doi.org/10.1200/JCO.2005.06.032 PMID: 16192590

15. Celaya M.O., et al., Travel distance and season of diagnosis affect treatment choices for women with early-stage breast cancer in a predominantly rural population (United States). Cancer Causes Control, 2006. 17(6): p. 851–6. https://doi.org/10.1007/s10552-006-0025-7 PMID: 16783613

16. Voti L., et al., Treatment of local breast carcinoma in Florida: the role of the distance to radiation therapy facilities. Cancer, 2006. 106(1): p. 201–7. https://doi.org/10.1002/cncr.21557 PMID: 16783613

17. Atthas W.F., et al., Travel distance to radiation therapy and receipt of radiotherapy following breast-conserving surgery. J Natl Cancer Inst, 2000. 92(3): p. 269–71. https://doi.org/10.1093/jnci/92.3.269 PMID: 10955446

18. Meden T., et al., MSJAMA, Relationship between travel distance and utilization of breast cancer treatment in rural northern Michigan. Jama, 2002. 287(1): p. 111. PMID: 11754721

19. Nattinger A.B., et al., Relationship of distance from a radiotherapy facility and initial breast cancer treatment. J Natl Cancer Inst, 2001. 93(17): p. 1344–6. https://doi.org/10.1093/jnci/93.17.1344 PMID: 11358710

20. Boscoe F.P., et al., Geographic proximity to treatment for early stage breast cancer and likelihood of mastectomy. Breast, 2011. 20(4): p. 324–8. https://doi.org/10.1016/j.breast.2011.02.020 PMID: 21440439

21. Tracey E., et al., Patients with localized non-small cell lung cancer miss out on curative surgery with distance from specialist care. ANZ J Surg, 2015. 85(9): p. 658–63. https://doi.org/10.1111/ans.12855 PMID: 25267111

22. Lee B., et al., Effect of place of residence and treatment on survival outcomes in patients with diffuse large B-cell lymphoma in British Columbia. Oncologist, 2014. 19(3): p. 283–90. https://doi.org/10.1634/theoncologist.2013-0343 PMID: 24569946

23. Tracey E., et al., Effects of access to and treatment in specialist facilities on survival from epithelial ovarian cancer in Australian women: a data linkage study. Int J Gynecol Cancer, 2014. 24(7): p. 1232–40. https://doi.org/10.1097/IGC.0000000000000213 PMID: 25153678

24. Baade P.D., et al., Distance to the closest radiotherapy facility and survival after a diagnosis of rectal cancer in Queensland. Med J Aust, 2011. 195(6): p. 350–4. https://doi.org/10.5894/mja1.11204 PMID: 21929501

25. Jong K.E., et al., Remoteness of residence and survival from cancer in New South Wales. Med J Aust, 2004. 180(12): p. 618–22. https://doi.org/10.5694/j.1326-5377.2004.tb06123.x PMID: 15200358
26. Thomas A.A., et al., Distance from treating hospital and colorectal cancer survivors’ quality of life: a gendered analysis. Support Care Cancer, 2015. 23(3): p. 741–51. https://doi.org/10.1007/s00520-014-2407-9 PMID: 25179691

27. Ambrogi M., et al., Distance as a Barrier to Cancer Diagnosis and Treatment: Review of the Literature, in Oncologist. 2015. p. 1378–85. https://doi.org/10.1634/theoncologist.2015-0110 PMID: 26512045

28. Bristow R.E., et al., Spatial analysis of adherence to treatment guidelines for advanced-stage ovarian cancer and the impact of race and socioeconomic status. Gynecol Oncol, 2014. 134(1): p. 60–7. https://doi.org/10.1016/j.ygyno.2014.03.561 PMID: 24680770

29. Meilleur A., et al., Rural Residence and Cancer Outcomes in the US: Issues and Challenges. Cancer Epidemiol Biomarkers Prev, 2013. 22(10).

30. @NAACCR, GIS Resources. 2019.

31. Flytkjaer Virgilsen L., Moller H., and Vedsted P., Cancer diagnostic delays and travel distance to health services: A nationwide cohort study in Denmark. Cancer Epidemiol, 2019. 59: p. 115–122. https://doi.org/10.1016/j.canep.2019.01.018 PMID: 30738824

32. Dai D., Black residential segregation, disparities in spatial access to health care facilities, and late-stage breast cancer diagnosis in metropolitan Detroit. Health Place, 2010. 16(5): p. 1038–52. https://doi.org/10.1016/j.healthplace.2010.06.012 PMID: 20630792

33. Jones A.P., et al., Travel times to health care and survival from cancers in Northern England. Eur J Cancer, 2008. 44(2): p. 269–74. https://doi.org/10.1016/j.ejca.2007.07.026 PMID: 17886651

34. Punglia R.S., et al., Effect of distance to radiation treatment facility on use of radiation therapy after mastectomy in elderly women. Int J Radiat Oncol Biol Phys, 2006. 66(1): p. 56–63. https://doi.org/10.1016/j.ijrobp.2006.03.059 PMID: 16814955

35. Lin C.C., et al., Association Between Geographic Access to Cancer Care and Receipt of Radiation Therapy for Rectal Cancer. Int J Radiat Oncol Biol Phys, 2016. 94(4): p. 719–28. https://doi.org/10.1016/j.ijrobp.2015.12.012 PMID: 26972644

36. Sparling A.S., et al., Is distance to chemotherapy an obstacle to adjuvant care among the NC. Medicaid-enrolled colon cancer patients? J Gastrointest Oncol, 2016. 7(3): p. 336–44. https://doi.org/10.21037/jgo.2016.02.01 PMID: 27284464

37. Lin C.C., et al., Association Between Geographic Access to Cancer Care, Insurance, and Receipt of Chemotherapy: Geographic Distribution of Oncologists and Travel Distance. J Clin Oncol, 2015. 33(28): p. 3177–85. https://doi.org/10.1200/JCO.2015.61.1558 PMID: 26304878

38. Chou S., Deily M.E., and Li S., Travel distance and health outcomes for scheduled surgery. Med Care, 2014. 52(3): p. 250–7. https://doi.org/10.1097/MLR.000000000000082 PMID: 24374426

39. Barrington D.A., et al., Distance from a Comprehensive Cancer Center: A proxy for poor cervical cancer outcomes? Gynecol Oncol, 2016. 143(3): p. 617–621. https://doi.org/10.1016/j.ygyno.2016.10.004 PMID: 27720232

40. Turner M., et al., A cancer geography paradox? Poorer cancer outcomes with longer travelling times to healthcare facilities despite prompter diagnosis and treatment: a data-linkage study. Br J Cancer, 2017. 117(3): p. 439–449. https://doi.org/10.1038/bjc.2017.180 PMID: 28641316

41. Vetterlein M.W., et al., Impact of travel distance to the treatment facility on overall mortality in US patients with prostate cancer. Cancer, 2017. 123(17): p. 3241–3252. https://doi.org/10.1002/cncr.30744 PMID: 28472547

42. Murage P., et al., Impact of travel time and rurality on presentation and outcomes of symptomatic colorectal cancer: a cross-sectional cohort study in primary care. Br J Gen Pract, 2017. 67(660): p. e460–e466. https://doi.org/10.3399/bjgp17X691349 PMID: 28583943

43. Tanaka R., et al., Influence of Distance from Home to Hospital on Survival among Lung Cancer Patients, in Asian Pac J Cancer Prev. 2016. p. 5025–30. https://doi.org/10.22034/APJCP.2016.17.11.5025 PMID: 28032734

44. Gunderson C.C., et al., Distance traveled for treatment of cervical cancer: who travels the farthest, and does it impact outcome? Int J Gynecol Cancer, 2013. 23(6): p. 1099–103. https://doi.org/10.1097/IGC.0b013e3182989464 PMID: 23765207

45. Takenaka T., et al., Influence of the distance between home and the hospital on patients with surgically resected non-small-cell lung cancer. Eur J Cardiothorac Surg, 2016. 49(3): p. 842–6. https://doi.org/10.1093/ejcts/ezv253 PMID: 26201956

46. Charlton M.E., et al., Is travel time associated with late-stage colorectal cancer among Medicare beneficiaries in Iowa? J Rural Health, 2016. 32(4): p. 363–73.

47. Campbell N.C., et al., Impact of deprivation and rural residence on treatment of colorectal and lung cancer. Br J Cancer, 2002. 87(6): p. 585–90. https://doi.org/10.1038/bjc.6600515 PMID: 12237766
48. Arcury T.A., et al., Access to transportation and health care utilization in a rural region. J Rural Health, 2005. 21(1): p. 31–8. https://doi.org/10.1111/j.1748-0361.2005.tb00059.x PMID: 15667007

49. Peipins L.A., et al., Racial disparities in travel time to radiotherapy facilities in the Atlanta metropolitan area. Soc Sci Med, 2013. 89: p. 32–8. https://doi.org/10.1016/j.socscimed.2013.04.018 PMID: 23726213

50. Peipins L.A., et al., Time and Distance Barriers to Mammography Facilities in the Atlanta Metropolitan Area. J Community Health, 2011. 36(4): p. 675–83. https://doi.org/10.1007/s10900-011-9359-5 PMID: 21267639

51. Probst J.C., et al., Effects of residence and race on burden of travel for care: cross sectional analysis of the 2001 US National Household Travel Survey. BMC Health Serv Res, 2007. 7: p. 40. https://doi.org/10.1186/1472-6963-7-40 PMID: 17349050

52. Onega T., et al., Geographic access to cancer care in the U.S. Cancer, 2008. 112(4): p. 909–18. https://doi.org/10.1002/cncr.23229 PMID: 18189295

53. California, S.o. California Cancer Registry. 2016; http://www.ccrcal.org/.

54. Asch, S.M., et al., Quality of Care for Oncologic Conditions and HIV. 2000.

55. CoC Quality of Care Measures. 2019; https://www.facs.org/quality-programs/cancer/ncdb/qualitymeasures.

56. Haynes R., et al., Validation of travel times to hospital estimated by GIS, in Int J Health Geogr. 2006. p. 40. https://doi.org/10.1186/1476-072X-5-40 PMID: 16984650

57. Boscoe F.P., Henry K.A., and Zdeb M.S., A Nationwide Comparison of Driving Distance Versus Straight-Line Distance to Hospitals. Prof Geogr, 2012. 64(2). https://doi.org/10.1080/00330124.2011.583586 PMID: 24273346

58. Lu H., et al., Quantifying spatial accessibility in public health practice and research: an application to on-premise alcohol outlets, United States, 2013, in Int J Health Geogr. 2018. https://doi.org/10.1186/s12942-018-0143-y PMID: 29945619

59. Connect Origins to Destinations ArcGIS Online Help | Documentation. 2020; https://doc.arcgis.com/en/arcgis-online/analyze/connect-origins-to-destinations.htm.

60. Gomez S.L., et al., Hospital Policy and Practice Regarding the Collection of Data on Race, Ethnicity, and Birthplace. https://doi.org/10.2105/AJPH.93.10.1685, 2011. PMID: 14534222

61. Socioeconomic status and breast cancer incidence in California for different race/ethnic groups | Spring-erLink. 2018.

62. USDA ERS—Rural-Urban Continuum Codes. 2020; https://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx #.U0VBhleG-Hs.

63. Rubin, D.B. and H.U. Department of Statistics, Multiple Imputation for Nonresponse in Surveys. 1987.

64. ©NCICancerStats, Methods for Measuring Cancer Disparities—Relevant to Healthy People 2010 Objectives—SEER Publications. 2019.

65. Wheeler S., et al., Effects of distance to care and rural or urban residence on receipt of radiation therapy among North Carolina Medicare enrollees with breast cancer. North Carolina medical journal, 2014. 75 (4). https://doi.org/10.18043/ncm.75.4.239 PMID: 25046086

66. Spees L., et al., Evaluating the urban-rural paradox: The complicated relationship between distance and the receipt of guideline-concordant care among cervical cancer patients. Gynecologic oncology, 2019. 152(1). https://doi.org/10.1016/j.gyno.2018.11.010 PMID: 30442384

67. Spees L., et al., Examining Urban and Rural Differences in How Distance to Care Influences the Initiation and Completion of Treatment among Insured Cervical Cancer Patients. Cancer epidemiology, biomarkers & prevention: a publication of the American Association for Cancer Research, cosponsored by the American Society of Preventive Oncology, 2019. 28(5). https://doi.org/10.1158/1055-9965.EPI-18-0945 PMID: 30733307

68. Merritt R., et al., Racial Disparities in Overall Survival and Surgical Treatment for Early Stage Lung Cancer by Facility Type. Clinical lung cancer, 2021. https://doi.org/10.1016/j.clc.2021.01.007 PMID: 33597104

69. Merritt R., et al., The Academic Facility Type Is Associated With Improved Overall Survival for Early-Stage Lung Cancer. The Annals of thoracic surgery, 2021. 111(1). https://doi.org/10.1016/j.athoracsur.2020.05.051 PMID: 32615092

70. Health, N.R.C., 2019 Healthcare Consumer Trends Report. 2019.

71. Natale-Pereira A., et al., The role of patient navigators in eliminating health disparities. Cancer, 2011. 117(15 Suppl). https://doi.org/10.1002/cncr.26264 PMID: 21780089

72. Burg m., et al., Barriers to accessing quality health care for cancer patients: a survey of members of the association of oncology social work. Social work in health care, 2010. 49(1). https://doi.org/10.1080/00981380903018470 PMID: 20077318