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Residential Distance to the Cancer Center and Outcomes after Robotic-Assisted Pulmonary Lobectomy

Allison O. Dumitriu Carcoana [b], Jenna C. Marek [b], William J. West III [b], Cole R. Fiedler [b], William N. Doyle Jr. [b], Kristie M. Labib [b], Lauren C. Ladehoff [b], Jose A. Malavet [b], Gregory Fishberger [b], Carla C. Moodie [a], Joseph R. Garrett [a], Jenna R. Tew [a], Jobelle J.A.R. Baldonado [a,c,d], Jacques P. Fontaine [a,c,d], Eric M. Toloza [a,c,d,*]

[a] Department of Thoracic Oncology, Moffitt Cancer Center, Tampa, FL, USA
[b] Department of Medical Education, University of South Florida Health Morsani College of Medicine, Tampa, FL, USA
[c] Department of Surgery, University of South Florida Health Morsani College of Medicine, Tampa, FL, USA
[d] Department of Oncologic Sciences, University of South Florida Health Morsani College of Medicine, Tampa, FL, USA

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ABSTRACT

Background: Outcomes of lung cancer patients traveling greater distances for surgical oncology care are not well-described. We investigated the effects of increased travel burden after robotic-assisted pulmonary lobectomy (RAPL) for lung cancer.

Methods: Clinical characteristics and surgical outcomes of 711 consecutive patients who underwent RAPL from September 2010 to March 2022 were compared, stratified by primary residential ZIP code <160 km or ≥160 km from the cancer center.

Results: Of 711 study patients, 515 (72.4%) lived within 160 km and 196 (27.6%) lived ≥160 km away. There were no differences in Charlson Comorbidity Index scores or tumor characteristics. Those traveling ≥160 km experienced more unfavorable perioperative outcomes and postoperative complications, and had worse median survival time by 1.68 years, but this survival difference did not reach statistical significance.

Conclusions: With the growing centralization of cancer care, travel burden may emerge as a predictor of surgical oncology outcomes.

INTRODUCTION

Lung cancer causes approximately 350 deaths per day in the United States, where it is the most significant cause of cancer mortality and second leading cause of death overall.[1] Non-small cell lung cancer (NSCLC) is the most common type, as it is clinically estimated to affect 80% of lung cancer patients. The ideal treatment for NSCLC is radical resection, because resection of stage-I disease may improve five-year overall survival (OS) by 77%, and resection of stage-III cancer may increase five-year OS by 31%.[2,3] Less than 5% of patients with stage I-III NSCLC will survive up to five years without treatment.[3] Fifty percent of NSCLC patients in the United States have stage IV cancer at the time of diagnosis with distant organ metastasis that may preclude surgery. Patients with multi-organ metastasis are not considered candidates for lobectomy and receive systemic therapies, including chemotherapy, radiotherapy, targeted therapy, or immunotherapy.[2] The overall cure and survival rates for patients with NSCLC remain low despite advances in systemic therapy options for treatment.[4]

Interventions targeted at earlier detection and treatment of cancer are important for facilitating reductions in NSCLC mortality.[1] For the greatest impact, interventions should be directed at high-risk groups with greater burdens of NSCLC morbidity and mortality.[5,6] One barrier for patients who need lung cancer therapy is geographical access to care. Several studies have analyzed the effects of increased travel burden on cancer diagnosis, treatment, and outcomes.[7–18] Some studies report higher cancer stage at diagnosis or worse outcomes in patients with more significant travel time,[7,9-14,16-19] but others have found better outcomes or no difference in outcomes and survival in patients traveling a greater distance.[8,10,13,15,20,21]

Studies done specifically in lung cancer patients reported that those

* Corresponding author at: 12902 USF Magnolia Drive, Suite CSB-6 (ThorProg), Tampa, FL 33612 USA.
E-mail address: eric.toloza@moffitt.org (E.M. Toloza).

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with increased travel distance to the hospital had less access to curative surgery for NSCLC,[17] and those with more significant travel burdens who did receive surgery had increased hospital length of stay (LOS).[14] One study showed that greater travel times were associated with a more advanced lung cancer stage at diagnosis,[18] but another reported a less advanced stage at diagnosis.[10]

It may be important for cancer centers in different regions to assess how increased travel burden affects outcomes in their patient population, as no clear trend has been established nationwide. Furthermore, the effect of increased travel burdens on long-term outcomes has not been assessed in lung cancer patients, despite the high morbidity and mortality in this population. The purpose of this study was to assess whether there was a relationship between travel distance and outcomes after robotic-assisted pulmonary lobectomy (RAPL) for NSCLC at a large-volume comprehensive cancer center. We hypothesize that patients with greater travel burdens would experience more unfavorable outcomes. If this hypothesis is true, then the present study will have important implications for patient care, including support for patient-physician discussions on patient travel burden and plans to mitigate significant travel burdens in the perioperative and postoperative periods on a case-by-case basis.

MATERIALS AND METHODS

We retrospectively reviewed consecutive patients who underwent robotic-assisted pulmonary lobectomy by one surgeon from September 2010 through March 2022 at a single NCI-designated cancer center. Data were extracted from our hospital's electronic medical records and entered into a database on the institution's secure network. Our institution's Scientific Review Committee and our university's Institutional Review Board approved this study protocol and waived the requirement to obtain informed consent. Eligible patients in this study were ≥18 years of age and had undergone elective RAPL for clinically diagnosed lung cancer, with or without neoadjuvant therapy. The surgical procedure for RAPL in patients with clinically suspected or diagnosed lung cancer was carried out with the da Vinci® S™, Si™, or Xi™ robotic surgical systems (Intuitive Surgical Corp., Sunnyvale, CA, USA) by the procedure described in Deol et al.[25]

The independent variable was the residential distance from the cancer, stratified as either <160 or ≥160 kilometers (km), or approximately 100 miles, from the cancer center. We used patients' residential ZIP codes to approximate the location of their primary residence. Each ZIP code was entered into Google Maps, and the distance from that ZIP code to our cancer center was calculated. We chose 160 km (160 kilometers) as the cutoff based on studies done at urban, academic or large-volume cancer centers similar to ours.[12,16,26] Using the shortest driving route options in Google Maps, patients traveling at least 160 km from their primary residential ZIP code had a minimum travel time of approximately 90 minutes if using highways.

Patient characteristics including age, sex, race, body mass index (BMI), preoperative forced expiratory volume in one second as a percentage of predicted (FEV1%), and clinically relevant past medical history were collected. Patients who quit smoking within three months prior to surgery and those who were actively smoking at the time of surgery were considered current smokers. Those who had quit more than three months prior to surgery were considered former smokers. Charlson Comorbidity Index (CCI) score, a validated tool used to estimate the risk of 10-year mortality from comorbid diseases, was used as a summary comorbidity measure. CCI has been assessed as a better predictor of long-term survival than individual comorbid conditions in patients who undergo surgery for NSCLC.[27] Tumor characteristics, including size, histology, grade, nodal status, and pathologic stage, were compared between the study groups.

The frequencies of intraoperative complications were analyzed. Perioperative outcomes were evaluated by skin-to-skin operative time, estimated blood loss, overall and urgent conversion to open lobectomy, chest tube duration, discharge with chest tube valve, hospital LOS, discharge disposition, and in-hospital and 30-day mortality. Patient disposition at discharge was categorized as favorable (transfer to home with self-care or with home health nursing and/or physical therapy) or unfavorable (long-term acute care facility, rehabilitation facility, hospice, or expiration). Clinically relevant postoperative pulmonary and cardiovascular complications, adverse outcomes requiring medical intervention, and 10-year overall survival were also compared. For survival analysis, the date of last follow-up was defined as the date a patient was last seen in clinic, last contacted, or their date of death. Kaplan-Meier curves were generated to estimate OS with 95%

Table 1
Patient demographics.

Variables	<160 km (n = 515)	≥160 km (n = 196)	*p* value
Age*, y	69.0 ± 0.4 (24-93)	68.0 ± 0.7 (34-88)	0.4811
BMI*, kg/m^2	28.3 ± 0.3 (14.0-60.1)	27.0 ± 0.4 (16.8-47.0)	0.0064
FEV1%*	89.1 ± 0.8 (32-145)	88.3 ± 1.5 (34-147)	0.6052
Sex			
Male	231 (44.8%)	86 (43.9%)	0.8149
Female	284 (55.2%)	110 (56.1%)	-
Race			
White	474 (92.0%)	187 (95.4%)	0.5126
African American	15 (2.9%)	4 (2.0%)	-
Asian or Pacific Islander	11 (2.1%)	1 (0.5%)	-
Native American	2 (0.4%)	1 (0.5%)	-
Other/multiracial	12 (2.3%)	3 (1.5%)	-

* Mean ± standard error of the mean (range); BMI = body mass index; FEV1% = forced expiratory volume in one second as percent of predicted.

Table 2
Smoking status and comorbidities.

Variables	<160 km (n = 515)	≥160 km (n = 196)	*p* value
Smoking Status			
Current Smokers	102 (19.8%)	25 (12.8%)	0.0479
Former Smokers	313 (60.8%)	137 (69.9%)	-
Non-Smokers	99 (19.2%)	34 (17.4%)	-
Pulmonary-Related Comorbidities			
Asthma	35 (6.8%)	15 (7.7%)	0.6896
COPD	105 (20.4%)	45 (23.0%)	0.4528
Obstructive Sleep Apnea	36 (6.8%)	20 (10.7%)	0.1552
Pneumonia	45 (8.7%)	8 (4.1%)	0.0347
Pulmonary Embolism/DVT	18 (3.5%)	6 (3.1%)	0.7747
Pulmonary Fibrosis	10 (1.9%)	6 (3.1%)	0.3685
Cardiovascular Comorbidities			
Atrial Fibrillation	43 (8.4%)	18 (9.2%)	0.7227
Other Arrhythmias	101 (19.6%)	32 (16.3%)	0.3155
Carotid Stenosis	21 (4.1%)	11 (5.6%)	0.3788
Cerebrovascular Accident	25 (4.9%)	8 (4.1%)	0.6581
Congestive Heart Failure	9 (1.8%)	4 (2.0%)	0.7943
CAD/Myocardial Infarction	86 (16.7%)	29 (14.8%)	0.5249
Hyperlipidemia	240 (46.6%)	80 (40.8%)	0.1659
Hypertension	304 (59.0%)	100 (51.0%)	0.0628
Peripheral Vascular Disease	25 (4.9%)	14 (7.1%)	0.2311
Other Comorbidities			
Bleeding disorders	12 (2.3%)	5 (2.6%)	0.8661
Chronic anemia	15 (2.9%)	8 (4.1%)	0.4311
Gastroesophageal Reflux Disease	125 (24.3%)	48 (2.4%)	0.9622
Pancreatitis	11 (2.1%)	5 (2.6%)	0.7388
Diabetes mellitus	89 (17.3%)	29 (14.8%)	0.4260
Cirrhosis or liver failure	4 (0.8%)	0 (0.0%)	0.2160
Chronic Kidney Disease	28 (5.4%)	4 (2.0%)	0.0505
Previous cancer	223 (43.3%)	80 (40.8%)	0.5843
Charlson Comorbidity Index *	0.81 ± 0.04 (0-4)	0.78 ± 0.07 (0-3)	0.7125

* Mean ± standard error of the mean (range). COPD = chronic obstructive pulmonary disease; DVT = deep vein thrombosis; CAD = coronary artery disease.

Table 3
Tumor characteristics.

Variables	<160 km (n = 515)	≥160 km (n = 196)	*p* value
Tumor size*, cm	3.2 ± 0.1 (0.5-11.0)	3.2 ± 0.2 (0.2-14.2)	0.7484
Pathology			
Primary lung cancer	475 (92.2%)	181 (92.3%)	0.7143
Pulmonary metastasis	31 (6.0%)	10 (5.1%)	-
Other pathology	9 (1.8%)	5 (2.6%)	-
Primary Lung Cancer Histology			
Adenocarcinoma	297 (57.7%)	126 (64.3%)	0.3835
Squamous cell carcinoma	109 (21.2%)	33 (16.8%)	-
Neuroendocrine tumor	50 (9.7%)	15 (7.6%)	-
Other	22 (4.3%)	9 (4.6%)	-
Grade of Differentiation			
Well-differentiated	119 (23.1%)	47 (24.4%)	0.6357
Moderate-differentiated	210 (40.8%)	82 (41.6%)	-
Poorly-differentiated	141 (27.4%)	51 (25.9%)	-
Undifferentiated	4 (0.8%)	0 (0.0%)	-
Nodal Status			
N0	325 (63.1%)	118 (60.2%)	0.5268
N1	58 (11.3%)	28 (14.3%)	-
N2	89 (17.3%)	33 (16.8%)	-
Pathologic Stage			
IA	170 (33.0%)	69 (35.2%)	0.5430
IB	70 (13.6%)	17 (8.7%)	-
IIA	27 (5.2%)	11 (5.6%)	-
IIB	73 (14.2%)	30 (15.3%)	-
IIIA	84 (16.3%)	35 (17.9%)	-
IIIB	26 (5.1%)	7 (3.6%)	-

* Mean ± standard error of the mean (range).

confidence intervals.

We reported mean ± standard error of the mean (SEM), or else median and first and third quartile (Q1, Q3) values, for continuous variables and frequency (percentage) for categorical variables. Variables that did not follow a normal distribution curve were reported as median (Q1, Q3). The statistical tests used to compare variables were Student's *t*-test for continuous variables, Wilcoxon rank-sum for variables that did not follow a normal distribution, and Pearson chi-square or Fisher's exact test for categorical variables. Kaplan-Meier curves were generated to compare OS, and a Cox regression analysis was used for survival analysis. Log-rank test was used to compare median OS time between patients traveling <160 km versus ≥160 km to the cancer center.

RESULTS

The data described above were collected for 719 patients who underwent RAPL by one surgeon from September 2010 to March 2022. Eight patients were excluded from the study due to incomplete data, resulting in a total of 711 study patients. The final cohort was divided into two groups for analysis. Of the 711 patients, 515 (72.4%) lived <160 km and 196 (27.6%) lived ≥160 km from the cancer center.

Patient demographics and preoperative comorbidities

Patients living within 160 km of the cancer center had a higher average BMI of 28.3 ± 0.3 kg/m^2 (range, 14.0 – 60.1 kg/m^2) compared to those living more than 160 km away (27.0 ± 0.4 kg/m^2; range, 16.8 – 47.0 kg/m^2; p value = 0.0064; Table 1). There were no differences in age (p = 0.4811), male-to-female sex distribution (p = 0.8149), race (p = 0.5126), or FEV1% (p = 0.6052) between the groups.

There were more current smokers and non-smokers in the <160 km group compared to the ≥160 km group (19.8% vs 12.8% and 19.2% vs 17.4%, respectively) and fewer former smokers in the <160 km compared to the ≥160 km group (60.8% vs 69.9%, respectively; p = 0.0479; Table 2). The <160 km group also had a higher prevalence of preoperative pneumonia than the ≥160 km group (8.7% vs 4.1%, respectively, p = 0.0347; Table 2). There were no other differences in the distribution of comorbid conditions, nor did the Charlson Comorbidity Index scores differ significantly between groups (p = 0.7125). Tumor size (p = 0.7484), histology (p = 0.3835), grade (p = 0.6357), nodal status (p = 0.5268), and pathologic stage (p = 0.5430) did not differ significantly between the groups (Table 3).

Table 4
Intraoperative complications.

Variables	<160 km (n = 515)	≥160 km (n = 196)	*p* value
Patients with Intraoperative Complications	28 (5.5%)	13 (6.6%)	0.5490
Bleeding (PA)	11 (2.1%)	6 (3.1%)	0.4729
Bleeding (PV)	8 (1.6%)	2 (1.0%)	0.5879
Bleeding (Other)	4 (0.8%)	4 (2.0%)	0.1542
Phrenic Nerve Injury	0 (0.0%)	1 (0.5%)	0.1055
Recurrent Laryngeal Nerve Injury	0 (0.0%)	1 (0.5%)	0.1051
Tracheal/Bronchial Injury	5 (1.0%)	2 (1.0%)	0.9542
Diaphragm Injury	1 (0.2%)	0 (0.0%)	0.5366
Robotic-Associated Complications	23 (4.5%)	10 (5.1%)	0.7226

PA = pulmonary artery; PV = pulmonary vein.

Table 5
Perioperative outcomes.

Variables	<160 km (n = 515)	≥160 km (n = 196)	*p* value
Estimated Blood Loss, mL*	130 [50, 200]	118 [50, 300]	0.1511
Skin-to-Skin Operative Time, min*	171 [144, 208]	181 [147, 235]	0.0343
Chest Tube Duration, d*	3 [2, 6]	4 [3, 7]	0.0311
Hospital Length of Stay, d*	4 [3, 6]	5 [3, 8]	0.0075
Overall Conversions to Thoracotomy	23 (4.8%)	15 (7.7%)	0.0925
Urgent Conversions to Thoracotomy	9 (1.8%)	5 (2.6%)	0.4908
Discharged with Chest Tube Valve	42 (8.2%)	20 (10.2%)	0.3910
*Favorable Disposition***	499 (96.9%)	188 (95.9%)	0.5231
*Unfavorable Disposition****	16 (3.1%)	8 (4.1%)	0.5231
In-Hospital Mortality	7 (1.4%)	4 (2.0%)	0.5105
30-Day mortality	9 (1.8%)	4 (2.0%)	0.7993

* Median [first quartile, third quartile];
** Home with self-care or with home health;
*** Transferred to long-term acute care or rehabilitation facility, discharged to assisted-living facility or to hospice, or died.

Intraoperative complications

There was no difference in the number of patients who experienced intraoperative complications (p = 0.5490; Table 4). Those traveling <160 and ≥160 km experienced similar rates of pulmonary artery bleeding (p = 0.4729), pulmonary vein bleeding (p = 0.5879), other sources of bleeding (p = 0.1542), phrenic nerve injury (p = 0.1055), recurrent laryngeal nerve injury (p = 0.1051), tracheal or bronchial injury (p = 0.9542), diaphragm injury (p = 0.5366), and robotic-associated complications (p = 0.7226; Table 4).

Perioperative and postoperative outcomes

The patients with ZIP codes ≥160 km from the hospital had a higher burden of unfavorable perioperative outcomes, with a median skin-to-skin operative time of 181 minutes (vs 171 minutes in the <160 km group; p = 0.0343), median chest tube duration of 4 days (vs 3 days; p = 0.0311), and a 5-day median hospital LOS (vs 4 days; p = 0.0075; Table 5). Those living ≥160 km away also experienced a higher frequency of postoperative complications compared to patients living within a 160 km driving radius, with a higher incidence of mucous plugging that required intervention (7.7% vs 3.7%, respectively; p =

Table 6
Postoperative complications.

Variables	<160 km (n = 515)	≥160 km (n = 196)	*p* value
Pulmonary-related complications			
Hypoxia requiring home O2	10 (1.9%)	3 (1.5%)	0.7124
Pulmonary embolism	5 (1.0%)	0 (0.0%)	0.1658
Aspiration	11 (2.1%)	2 (1.0%)	0.3198
Mucous plug requiring intervention	19 (3.7%)	15 (7.7%)	0.0366
Pneumonia	39 (7.6%)	7 (3.6%)	0.0526
Respiratory failure requiring intervention	10 (1.9%)	6 (3.1%)	0.3705
Prolonged air leak for >5 days	105 (20.4%)	53 (27.0%)	0.0566
Pneumothorax after chest tube removal requiring intervention	9 (1.8%)	3 (1.5%)	0.8386
Effusion or Empyema	16 (3.1%)	15 (7.7%)	0.0080
Chyle leak	26 (5.1%)	6 (3.1%)	0.2515
Hemothorax	6 (1.7%)	1 (0.5%)	0.4343
Cardiovascular complications			
Hypotension	20 (3.9%)	4 (2.0%)	0.2226
Atrial fibrillation (A-fib)	89 (17.3%)	40 (20.4%)	0.3508
A-fib not present preoperatively	54 (10.5%)	26 (13.3%)	0.3026
Myocardial infarction	5 (1.0%)	0 (0.0%)	0.1658
Shock/multi-organ failure	5 (1.0%)	1 (0.5%)	0.5472
Cardiopulmonary arrest	1 (0.2%)	1 (0.5%)	0.4781
Cerebrovascular accident	1 (0.2%)	1 (0.5%)	0.4775

0.0366) and effusion or empyema (7.7% vs 3.1%, respectively; $p = 0.0080$; Table 6). There were no other significant differences in the distribution of outcomes between the two groups.

Survival analysis

Patients traveling ≥160 km from the ZIP code of their primary residence to the cancer center had worse median OS time compared to patients living within a 160 km radius, but this difference did not reach statistical significance (Fig. 1). The median OS time in patients living within 160 km of the cancer center was 6.7 years ± standard error of 0.6 years (95% Confidence interval [CI] = 5.5 – 7.9 years) compared to 5.1 ± 0.9 years (95% CI = 3.3 – 6.8 years) in those traveling ≥160 km (log-rank $p = 0.126$).

DISCUSSION

Other studies have reported inconsistent trends in the effects of travel burden on patient outcomes. Our data confirmed our hypothesis that greater travel burdens are associated with more unfavorable perioperative and postoperative outcomes, although with no significant difference in 10-year OS. The discordance among study results suggests that a variety of regional factors may play a role in the effect of travel burden on access to cancer care. For example, the regionalization of lung cancer surgery in North Carolina was associated with increased travel

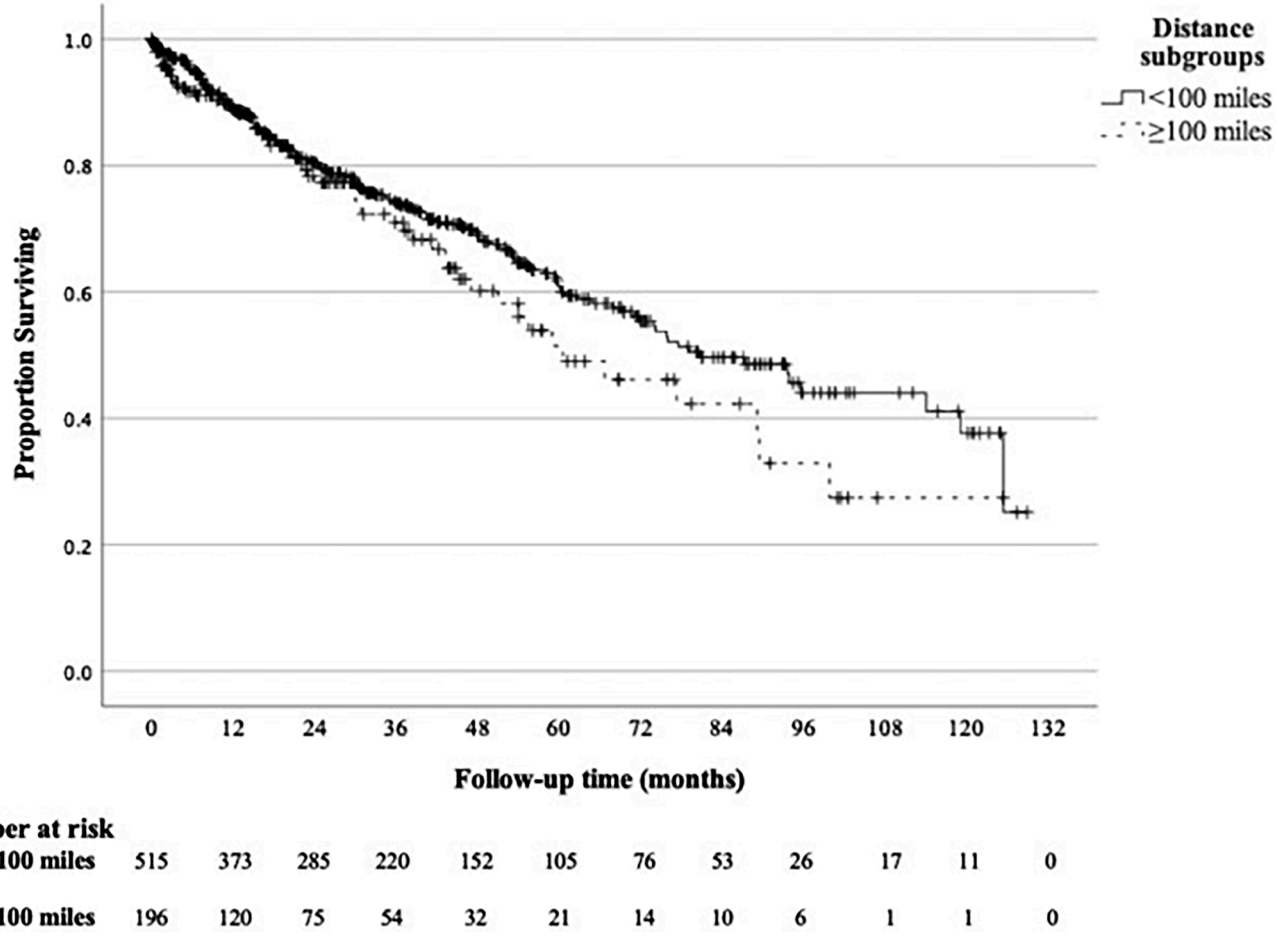

Fig. 1. Overall survival by travel distance <160 km vs. ≥160 km from the cancer center. Kaplan-Meier survival curves for patients with primary residential ZIP code <160 km (solid line) versus ≥160 km (dashed line) from the cancer center. The median overall survival time in patients living within 160 km of the cancer center was 6.73 years ± standard error of 0.62 years (95% Confidence interval [CI] = 5.53 – 7.94 years) compared to 5.05 ± 0.88 years (95% CI = 3.33 – 6.77 years) in those traveling ≥160 km (log-rank $p = 0.126$). The numbers at risk noted below the x-axis denote the number of patients still alive (i.e., not dead) and who have had follow-up (i.e., not censored) at each respective time point in the follow-up period.

burdens for patients from surrounding rural census areas but not for those from urban areas.[22] A study comparing rural and urban areas in New Hampshire and Vermont reported that distance from the cancer center determined whether lung cancer patients living in rural areas were referred to specialized care, but it was not the dominant determinant in urban parts of the states.[23] Also in New Hampshire, women with early-stage breast cancer were less likely to travel to radiation therapy appointments during the winter due to increased travel difficulty in cold weather conditions.[24]

Unlike other studies, wherein patients living at greater distances from a cancer center located in an urban environment were predominantly residents of rural areas, the group traveling ≥160 km in our cohort included rural residents as well as several patients traveling from census urban areas such as Jacksonville, Fort Myers, and Miami, FL. Those living within 160 km were either from the urban areas of Tampa and Orlando, FL, or surrounding rural census areas. Thus, patients in both study groups could have been residents of rural or urban census areas, such that the influences of urban and rural life on postoperative outcomes did not present a limitation in comparing our study groups.

Our study had other limitations, including the single-center, single-surgeon design. The cutoff of 160 km was chosen to indicate greater travel burden based on previous studies and local driving distances, but the degree of travel burden experienced by any one patient would be subjective and related to other personal factors, such as socioeconomic status and ownership of a personal vehicle, which we did not measure. There was also imbalance between the study groups, with the <160 km group (n = 515) having 2.6 times more patients than the ≥160 km group (n = 196). This analysis could be strengthened by a multi-center design, which could elucidate the effects of regional factors. Furthermore, a prospective study that captures individual differences by surveying participants on perioperative travel burden and the personal factors that influence their travel burden, including socioeconomic status, ownership of a personal vehicle, and care received at other sites is warranted.

CONCLUSIONS

Increased travel burden, defined by primary residential zip codes ≥160 km from the cancer center, was associated with a greater burden of unfavorable perioperative outcomes and postoperative complications in our cohort. With the growing centralization of cancer care, travel burden may emerge as a predictor of surgical oncology outcomes. The authors recommend that surgical teams initiate discussions with patients regarding travel burden. Further research is needed to understand whether personal or regional factors related to travel burden affect surgical outcomes at comprehensive cancer centers.

Ethical Statement

The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Ethical approval to report this study was obtained from our institution's Scientific Review Committee (MCC #16728, #18761, and #19304) and by our university's Institutional Review Boards (USF IRB #Pro00022263 and Chesapeake IRB #Pro00017745 and #00000790). Access to datasets is available upon request from the corresponding author.

Statement of Informed Consent

Informed consent for patient information to be published in this article was waived by our Institutional Review Boards for this retrospective study, which is considered a review of existing data. However, through our institutional surgical informed consent, patients gave permission to use surgery-related and tissue-related data for education and research purposes.

Declaration of Competing Interest

E.M.T. and J.P.F have had financial relationships with Intuitive Surgical Corp. in the form of honoraria received as robotic thoracic surgery observation sites and proctors. The other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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