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Differences in travel time to cancer surgery for colon versus rectal cancer in a rural state: A new method for analyzing time-to-place data using survival analysis

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Abstract

Introduction: Rectal cancer is rarer than colon cancer and is a technically more difficult tumor for surgeons to remove. Thus, rectal cancer patients may travel longer amounts of time for specialized treatment compared to colon cancer patients.

Methods: A secondary data analysis of colorectal cancer (CRC) incidence data from the Iowa Cancer Registry data was conducted. Travel times along a street network from all residential ZIP codes to all cancer surgery facilities were calculated using a geographic information system. A new method for analyzing “time-to-place” data using the same type of survival analysis method commonly used to analyze “time-to-event” data is introduced. Cox proportional hazard model was used to analyze travel time differences for colon versus rectal cancer patients.

Results: 5,844 CRC patients met inclusion criteria. Median travel time to the nearest surgical facility was 9 minutes, median travel time to the actual cancer surgery facilities was 22 minutes, and the median number of facilities bypassed was 3 facilities. While travel times to the nearest surgery facility were not significantly different for colon versus rectal cancer patients, rectal cancer patients traveled 15 minutes longer to their actual surgery facility and bypassed 2 more facilities to obtain surgery.

Discussion: In general, the survival analysis method used to analyze the time-to-place data as described here could be applied to a wide variety of health services and be used to compare travel patterns among different groups.

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Disclaimer

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CDC Research Determination

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Keywords

colorectal cancer; surgery; travel time; survival analysis

INTRODUCTION

While colorectal cancer (CRC) is often investigated as a single disease, the incidence, staging, treatment, surgical technical complexity, and long-term impact of rectal cancer is very different than that of colon cancer.[1–7] In the United States, there is approximately 1 rectal cancer for every 2.3 colon cancers; 44,180 new rectal cancer cases are expected in 2019 compared to 101,420 colon cancers.[8] Rectal cancer involves a more complex multi-modality approach to treatment compared to colon cancer. Potential morbidity (e.g., fecal incontinence, genitourinary dysfunction) secondary to surgery or surgical complications is higher due to anatomical challenges of the pelvis.[9–12] Given that rectal cancer is rarer, more difficult to treat, and has a greater risk and higher severity of complications, surgeons who specialize in colorectal cancer surgery can potentially reduce the adverse impact that this surgery can have on a patient's quality of life.[13] Studies have suggested that rectal cancer patients treated by colorectal surgeons have lower complication rates than those treated by general surgeons.[13,14]

Given that the risks of complications associated with rectal cancer surgery can be mitigated by receiving treatment from a board-certified colorectal surgeon, we may expect rectal cancer patients to travel to large or centralized institutions that employ, or have an affiliation with, colorectal surgeons, as opposed to be treated locally by general surgeons, resulting in relatively longer travel times compared to colon cancer patients. On the other hand, travel times to the actual cancer surgery facility used by rectal cancer patients that are not significantly different from colon cancer patients may indicate clinicians are referring rectal cancer patients to general surgeons in their community. In either case, the purpose of this study is to assess whether the travel time for cancer surgery was different for colon versus rectal cancer patients, and to demonstrate a new analytical method that can be used to evaluate similar comparisons in future research.

To do so required an effective method for detecting whether the observed travel times for colon versus rectal cancer patient were significantly different, after adjusting for covariates such as age, sex, stage, urban-rural status, and type of facility used. We accomplished this purpose by demonstrating a new way of using the Cox Proportional Hazard Model[15] to analyze time-to-place data. In this study, these data were measured as travel times from residential ZIP code to location of their nearest and actual cancer surgery facilities. This study builds on our previous study, which used Kaplan-Meier curves and log-rank tests to demonstrate that the travel time for Medicare beneficiaries who presented with late-stage colorectal cancer was not significantly different than the travel time for early-stage beneficiaries.[16] Survival analysis provides a method for assessing whether the durations in two or more groups are systematically longer for one group than other groups.[15] Like the time-to-event durations used in traditional survival analysis, the time-to-place durations used in this study are non-negative and not normally distributed and are thus suitable as

dependent variables in a survival analysis framework.[17] Other studies that analyze travel time statistics to health service facilities report descriptive differences, but they neither infer whether the differences were statistically significant nor adjust for potentially confounding covariates.[18–23] For example, distance to radiation therapy for cancer has been shown to vary by cancer treatment facility type.[22] Likewise, rural status plays an important role in travel time because rural populations are dispersed and providers tend to locate in more populated areas[16,19,22,24]; thus it is unavoidable that patients residing in rural areas travel further distances to health care service facilities than those who live in urban areas. Without the ability to adjust for these confounders, it is difficult to infer whether the observed travel time differences are genuine. The Cox model can include covariates while estimating the magnitude of the travel time differences between the two types of cancer patients. In general, the survival analysis method used to analyze the time-to-place data as described here could be for a wide variety of health services and be used to conclude whether one group of people traveled differently than another group.

METHODS

Data Sources

A secondary data analysis of all colon, recto-sigmoid and rectal cancer sites captured by the Iowa Cancer Registry (ICR) from 2010–2014 was conducted. The ICR is a population-based active surveillance registry that collects information on all cancer incidences in Iowa, which helps to ensure that the study findings are applicable to the entire population of Iowa. Since 1973, the ICR has captured cancer diagnoses among Iowans and is one of the original nine, out of the now twenty-one, National Cancer Institute's Surveillance, Epidemiology and End Results (SEER) population-based cancer registries.

Study Population

Our analytic cohort included all patients who resided in Iowa at the time of their malignant colon or rectal diagnosis between 2010 and 2014, received surgery in any state for their cancer, and had one of the following International Classification of Diseases for Oncology-3 (ICD-O-3) histologies: adenocarcinoma (8140, 8210–8211, 8213, 8220, 8240, 8243–8246, 8249, 8255, 8261, 8263, 8380), mucinous adenocarcinoma: (8480–8481), signet ring cell carcinoma (8490). Diagnosis codes were drawn from the ICD-O-3 topographies. Colon cancer was defined as ICD-10-CM codes C18.0, C18.2-C18.9, C19.9, C26.0 and rectal cancer was defined as C20.9. After applying the exclusion criteria detailed in Figure 1, each observation represents a unique patient. This study received approval by the University of Iowa Institutional Review Board.

Study variables

Patient characteristics—Patients were classified as having colon cancer if their cancer site was documented as colon or recto-sigmoid cancer and were classified as having rectal cancer only if their cancer was documented as rectal cancer. Patient characteristics included age at diagnosis (ages ≤64, 65–74, or ≥75 years), sex, American Joint Commission on Cancer (AJCC) stage (stages I-IV), and rural-urban status of patient residence (urban, large rural city, small rural town, and isolated small rural town). The type of hospital where

patients were treated for rectal cancer were classified according to the following hierarchical categories: 1) National Cancer Institute Designated Cancer Center (*NCI*), 2) Commission on Cancer accredited hospitals (*CoC*), 3) Critical access hospitals (typically having <25 beds and located at least 30 miles from the nearest hospital) *(CAH)*, 4) hospitals that do not have any of the above designations or CoC accreditation (Non-CoC). Rural status was defined using the Rural-Urban Commuting Area (RUCA) code of the residential ZIP Code at the time of diagnosis; RUCA codes were subdivided using "categorization B" as described by the developers of the RUCA classification system[25] which include urban-focused (urban), large rural city/town-focused (large rural), small rural town-focused (small rural), and isolated small rural town-focused (small rural) ZIP codes. Race/ethnicity was not included as a demographic variable because the population aged ≥40 years in Iowa was nearly 95.5% non-Hispanic white as of 2010.

Outcome variables—Primary outcomes included three travel measures for each colorectal cancer patient: 1) travel time from residence to nearest cancer surgery facility (*nearest*), 2) travel time from residence to actual cancer surgery facility used by the patients (*treatment*), and 3) the number of facilities that patients bypassed (i.e., facilities nearer to the patient's residence) to obtain surgery at their actual cancer surgery facility (*bypassed*). Patient origins (n=885) were imputed using the population-weighted ZIP Code Tabulation Area centroids[26] matched to the residential ZIP Code listed in the registry data. Surgical locations were address-level geocodes for any facility that performed any colorectal cancer surgery on an Iowa resident during the study period (n=136). An origin-destination (O/D) matrix of shortest travel times from the patient locations (origins) to all surgical facilities where the patient could have potentially been treated (destinations) was created. The travel measures assume travel by car along a street network whose length and speed limits are known. The *bypass* measure was derived by sorting the travel times to all facilities in the dataset and then reporting the rank of the actual cancer surgery facility used by the patient.

Data Analysis

A univariate analysis was conducted to determine if the proportion of cases diagnosed with colon versus rectal cancer differed by sex, age, year of diagnosis, histology, cancer sequence, stage at diagnosis, rural/urban status of patient, and type of cancer surgery facility. Then a series of survival-type analyses using the three travel measures as the dependent variables were performed. Kaplan-Meier (KM) curves were used to visually display how the three travel measure variables varied by cancer site. Log-rank tests were used to evaluate whether each of the three travel measures were significantly different for rectal cancer patients than for patients with colon cancer.[27] The Cox Proportional Hazards Model was used to measure the magnitude of the differences in each of the three travel measures by cancer site, after accounting for demographic and tumor characteristics. The interpretation of the HRs differs from those produced in traditional time-to-event analysis where HR > 1 typically indicates an adverse outcome, such as a shorter survival time than the other group. A time-to-place HR >1 indicates that patients traveled shorter amounts of time for their surgery or bypassed fewer cancer surgery facilities. An HR <1 indicates that patients traveled longer amounts of time. Table 1 describes the characteristics of HRs for time-to-

event versus time-to-place data. The univariate comparisons were considered significant at the $P < .05$ level using the Chi-square test.

Equation 1 shows the general form of the Cox Proportional Hazards Model. $X_1 \ldots X_k$ are a collection of independent variables and $h_0(t)$ is the baseline hazard at time t. The baseline hazard is the hazard for a person with the value 0 for all the predictor variables.

$$h(t \mid X) = h_o(t)\exp\left(\sum_{i=1} \beta_i X_i\right) \quad \text{Equation 1}$$

Seven Cox Models were conducted for each of the three travel measure variables for a total of 21 models. Cancer site entered the models as a binary indicator variable for all 21 models. Equation 2 shows the Cox model containing only the cancer site variable using colon cancer as the reference.

$$h(t|site) = h_o(t)\exp\left(\sum_{i=1} \beta_1 site_1\right) \quad \text{Equation 2}$$

For each of the three travel measure variables, Model 1 assessed whether they were significantly different for rectal versus colon cancer patients (reference = colon cancer). To determine whether sex, age, stage at diagnosis, rural/urban status of patient, or type of surgical facility modified the HR associated with the travel time for colon versus rectal patients, the covariates were individually added for Models 2–6: sex (reference = men) was the control variable for Model 2; age at diagnosis (reference = aged ≥75 years) was the control variable for Model 3; stage at diagnosis (reference = Stage I) was the control for Model 4; urban/rural status was the control variable for Model 5 (reference = urban), and cancer surgery facility type (reference = NCI designated cancer facilities) was the control variable for Model 6. Model 7 included all covariates. All models were considered significant at the $P < .05$ level.

To aid in the interpretation of the results, the HRs from Model 7 were converted into minutes to estimate the additional time one group traveled compared to the reference group or the number of additional facilities one group bypassed compared to the reference group, after adjusting for covariates. The statewide median travel times to nearest and actual cancer surgery facilities used by patients (in minutes) and median number of facilities bypassed were calculated. Equation 3 shows that the travel time estimates (e) were calculated by subtracting the product of the HR from the model multiplied by the statewide median from the statewide median. When HR <1, these estimates refer to the number of additional minutes (or number bypassed) patients traveled compared to the reference group. When HR >1, these estimates refer to the number of fewer minutes (or number bypassed) patients traveled compared to the reference group.

$$e = median(t) - (HR^{*}median(t)) \quad \text{Equation 3}$$

Materials

SAS version 9.4 (SAS Institute, Cary, NC) was used to extract cases from SEER*DMS at the Iowa Cancer Registry and create the patient dataset. The Network Analyst extension of ArcGIS 10.5.1 (ESRI, Redlands, CA) and ESRI Streetmap data were used to create an origin-destination matrix of travel time in minutes and rank order of travel time from each population-weighted ZIP Code Tabulation Area (ZCTA) centroid to each cancer surgery facility. The Kaplan-Meier Curves and the Cox Proportional Hazard Models were performed using STATA/SE 14.0 (StataCorp LP, College Station, TX).

RESULTS

There were 5,844 CRC patients who met inclusion criteria; 81.5% were diagnosed with colon cancer. Table 2 shows the demographic characteristics of these patients by cancer site. Among the sample of patients with CRC in our study, 50.7% were men. A significantly higher proportion of men were represented in the rectal cancer group (60.5%). The age at diagnosis varied significantly between those with colon and rectal cancer, as a higher proportion of rectal cancer patients were diagnosed in the youngest age category when compared to the colon cancer group. For CRC stage at diagnosis in the overall sample, stage II (31.1%) was the most common followed by stage III (30.0%), stage I (27.8%), and stage IV (11.2%). However, these stage distributions were significantly different for colon cancer and rectal cancer patients. Fewer colon cancer patients had stage I diagnoses than rectal cancer patients did (26.5% versus. 33.3%), and a larger proportion with colon cancer were diagnosed with stage IV cancer (12.1% versus 7.1%). Almost half of CRC patients resided in the urban-focused ZIP codes (45.8%), with the remaining rural patients distributed among large rural (15.3%), small rural (19.5%) and isolated rural. These urban-rural differences were not significant when stratified by colon versus rectal cancer. Over half of CRC patients received cancer surgery at a CoC hospital (56.3%), followed by a non-CoC hospital (26.0%), a critical access hospital (10.6%), and NCI-designated cancer center (7.1%). However, rectal cancer patients received surgery at critical access hospitals and non-CoC hospitals less often than colon cancer patients and used CoC and NCI-designated hospitals more often than colon cancer patients. Figure 2 shows that these proportions remained relatively constant regardless of the rural/urban status of the patient. Critical access hospitals are located at least 30 miles from the nearest hospital and are therefore rural. Although patients residing in urban ZIP codes could have traveled to a critical access hospital for surgery, the absence of bars for the urban category indicate that no urban patients did so.

The resulting HRs from the Cox Models are shown in Table 3. Patients with colon cancer were the reference group for all models. Model 1 shows the unadjusted HR for the three travel measures and Model 7 shows the model that includes age, sex, stage, urban/rural status of the patient, and type of hospital variables. For the three travel measures, the addition of covariates in Models 2–6 did not greatly reduce the HRs for the main predictor variable in the model (colon vs. rectal cancer). For travel time to actual surgery facility and for number of facilities bypassed, the HRs for the main predictor variable in Model 7, which included all covariates, were somewhat closer to the null (HR = 1) than in Model 1 but

remained statistically significant. HRs were calculated for year of diagnosis, histology, and cancer sequence, but were not statistically different and thus are not shown.

Table 3 shows that the median travel time to the nearest cancer surgery facility in Iowa was 9 minutes and was similar between colon and rectal cancer patients. The maximum travel time to the nearest cancer surgery facility for all patients was 46 minutes, but the maximum travel time for colon cancer patients was lower at 37 minutes. Figure 3 shows that the travel times to the nearest cancer surgery facilities for rectal cancer patients was not significantly different than for colon cancer patients (log-rank test: chi-square = 2.67, $P = .103$).

Travel time to nearest cancer surgery facility in Table 3 is an estimate of the magnitude of the difference between travel times to surgical facilities for colon versus rectal cancer patients after adjusting for covariates. The travel time to nearest cancer surgery facilities for rectal cancer patients (HR = 1.065, $P > .05$) was not significantly different than the travel time for colon cancer patients, nor did travel times to the nearest cancer surgery facilities differ by sex or stage at diagnosis. Age was associated with a small, but clinically insignificant effect on travel time to nearest cancer surgery facility; patients aged <65 years (HR = 0.926, $P < .01$) and patients aged 65 to 74 (HR = 0.917, $P < .01$) only traveled 1 minute longer than patients aged ≥75 years. Rural status and facility type were associated with the largest impact on travel time to nearest cancer surgery facility. When compared with patients residing in isolated rural-focused ZIP Codes, patients residing in small rural-focused ZIP Codes (HR = 2.790, $P < .001$) traveled 16 fewer minutes, patients residing in large rural-focused ZIP Codes (HR = 2.455, $P < .001$) traveled 13 fewer minutes, and patients residing in urban-focused ZIP Codes (HR = 1.837, $P < .001$) traveled 8 fewer minutes. Critical access hospitals (HR = 1.229, $P < .001$) and non-CoC hospitals (HR = 1.195, $P < .001$) were 2 minutes closer than the Commission on Cancer (CoC) accredited hospitals, but NCI-designated hospitals (HR = 0.776, $P < .001$) were almost 4 minutes further.

The median travel time to the actual cancer surgery facilities used by the patients for the whole sample was 22 minutes (Table 3). Median travel times were 20 minutes for colon cancer compared to 38 minutes for rectal cancer. The maximum travel time to the actual cancer surgery facilities was 359 minutes, but 95% of colon cancer patients traveled 209 minutes or less and 95% of rectal cancer cases traveled 262 minutes or less. Figure 3 shows that rectal cancer patients traveled significantly longer amounts of time to their actual cancer surgery facilities (log-rank test: chi-square = 171.55, $P < .001$). **Travel time to actual cancer surgery facility used by patient** (Table 3) provides an estimate of the magnitude of the difference, after adjusting for covariates. Rectal cancer patients (HR = 0.747, $P < .001$) traveled 6 minutes longer than colon cancer patients. Travel time to their actual cancer surgery facility did not vary significantly by stage at diagnosis. When compared with patients residing in isolated rural-focused ZIP Codes, patients residing in small rural-focused ZIP Codes (HR = 1.283, $P < .001$) traveled 6 fewer minutes to the actual cancer surgery facility used by the patients, patients residing in large rural-focused ZIP Codes (HR = 2.104, $P < .001$) traveled 24 fewer minutes, and patients residing in urban-focused ZIP Codes (HR = 1.837, $P < .001$) traveled 62 fewer minutes. Compared with patients treated at Commission on Cancer (CoC) accredited hospitals, patients treated at critical access hospitals (HR =

5.386, $P < .001$) traveled 96 fewer minutes, patients treated at non-CoC facilities (HR = 0.185, $P < .001$) traveled 18 additional minutes, and patients treated at NCI-designated hospitals (HR = 0.519, $P < .001$) traveled 11 additional minutes.

Colorectal cancer patients were treated at one of 136 surgical facilities in Iowa and neighboring states. Table 3 shows that Iowa patients bypassed a median of 3 facilities, but colon cancer patients only bypassed 2 treatment facilities, while rectal cancer cases bypassed 5. The maximum number of facilities bypassed by all patients was 135 facilities, but 95% of patients bypassed 33 or fewer facilities. However, 95% of colon cancer patients bypassed 27 or fewer facilities and 95% of rectal cancer patients bypassed 71 or fewer facilities. Figure 3 shows that rectal cancer patients bypassed more facilities than colon cancer patients (log-rank test: chi-square = 187.99, $P < .001$). **The number of cancer surgery facilities bypassed by patients** (Table 3) shows that after adjustment for covariates, rectal cancer patients (HR = 0.752, $P < .001$) only bypassed 1 additional facility than colon cancer patients. While the hazard ratios for age and sex were statistically significant, each group only bypassed one additional facility when compared to their respective reference group and the number of facilities bypassed did not vary significantly by stage at diagnosis. When compared with patients residing in isolated rural-focused ZIP Codes, patients residing in large rural-focused ZIP Codes (HR = 1.746, $P < .001$) bypassed 2 fewer facilities and patients residing in urban-focused ZIP Codes (HR = 2.466, $P < .001$) bypassed 4 fewer facilities. Compared with patients who were treated at Commission on Cancer (CoC) accredited hospitals, patients treated at critical access hospitals (HR = 4.686, $P < .001$) bypassed 11 fewer facilities, patients treated at non-CoC facilities (HR = 1.636, $P < .001$) bypassed 2 fewer facilities, and patients treated at NCI-designated hospitals (HR = 0.587, $P < .001$) bypassed 1 additional provider.

DISCUSSION

Patients with rectal cancer traveled longer amounts of time and bypassed more cancer surgery facilities than colon cancer patients, even though travel times to their nearest cancer surgery facility were not significantly different. These associations remained significant even after adjusting for age, sex, stage at diagnosis, urban/rural status, and cancer surgery facility designation. Our results suggest that rectal cancer patients are being referred more often to specialized colorectal surgeons compared to colon cancer patients, which is particularly promising in the context of the National Accreditation Program for Rectal Cancer that aims to improve quality of care for rectal cancer patients. It appears that diagnosing physicians may be aware of the evidence supporting the treatment of rectal cancer by specialized, high volume colorectal surgeons and are referring patients accordingly.

These results also demonstrate an adequate level of geographic accessibility to surgical facilities where colorectal cancer surgery can be performed (irrespective of volume or quality). In fact, patients from small rural-focused ZIP Codes had shorter travel times to their nearest cancer surgery facilities compared to other rural/urban classes; all the critical access hospitals located in most of Iowa’s rural counties performed at least one colorectal cancer surgery during the study period. Despite this overall level of accessibility to nearest facilities, rectal cancer patients still bypassed more facilities than colon cancer patients,

resulting in longer travel times. Furthermore, regardless of rural/urban residential status, rectal cancer patients bypassed more critical access hospitals, where colorectal surgeons do not typically practice.

This paper answers a novel and substantive question about differences in travel measures to surgery for colon versus rectal cancer. Use of Cox Proportional Hazards Models have been used to analyze differences in travel time data in transportation modeling research,[17,28] but its use in a health services research context is novel. The methods used in this study allowed us to compare travel meaures for two types of cancer patients while accounting for patient demographic characteristics, urban/rural residential status, and type of cancer surgery facility. Other health services researchers have used travel times in a survival analysis context, but time-to-event is treated as the dependent variable and travel time is treated as an explanatory variable.[29,30] Here, we treat the time-to-place durations as the dependent model in a Cox Proportional Hazard Models, which allows us to measure the magnitude of travel time differences after adjusting for covariates. Future research could improve upon this survival analysis approach of modeling travel times and estimating differences in travel time by testing whether different parametric survival models are more appropriate than the non-parametric Cox model. While the primary variable of interest (cancer site) did not violate the proportional hazards assumption, another improvement would be to ensure that all variables do not violate the proportional hazards assumption. For example, urban-rural status varies across space, which increases the likelihood that it violates the assumption. In this case, rural-urban status could be treated as a spatial-varying travel time adjustor analogous to a time-varying survival time adjustor rather than an explanatory variable in the model. Since rural patients are more geographically dispersed and facilities tend to be located in urban areas, rural patients naturally travel longer distances to obtain health care than urban patients.[19] The *bypass* measure is important because it is difficult to compare the choices made by rural patients when the travel times for rural patients are confounded by the respective geographic distributions of the population and the facilities. Note that the travel time to treatment facilities and the number of treatment facilities bypassed were highly correlated (Pearson's R = 0.913, $P < .001$). However, this correlation may be a function of the geographic accessibility to cancer surgery in Iowa; other states with a lower level of spatial accessibility could test whether this relationship is as strong and whether it varies by urban/rural status.

The data supporting these findings did not include colorectal cancer patients who did not seek care, which would be important in determining whether there were any barriers to surgical care for their colorectal cancer. We did not assess surgery outcomes, thus we do not know whether rectal cancer patients who were treated by a general surgeon actually had a higher risk of complications than rectal cancer patients who were treated by a colorectal surgeon. It is a reasonable assumption that that rectal cancer patients were more likely to be treated by colorectal surgeons, but without data about the surgeons, we can only speculate that the longer travel times and more bypassed hospitals is suggestive that the assumption is correct. Likewise, we did not assess the impact of insurance network restrictions or whether facility-level quality measures played a role in the travel time to actual surgery facility used by the patients.

In this novel study of cancer registry data, we used time-to-place data in a Cox Proportional Hazard Model framework to assess whether the travel time to cancer surgery for colon cancer patients was significantly different than travel time for rectal cancer patients. We found that patients with rectal cancer travel longer and bypass more facilities than patients with colon cancer. This may be due to differing referral patterns of diagnosing physicians, or because rectal cancer patients are aware of the different complication rates and risk associated with rectal cancer surgery and seek care or are guided to seek care with more highly specialized surgeons or facilities. Other states could conduct a similar analysis of colorectal cancer surgery patients as evidence that their clinicians are aware of the differences in the potential risks of rectal versus colon cancer surgery and effectively communicating those risks to their patients. In general, the survival analysis method used to analyze the time-to-place data as described here could be applied to a wide variety of health services and be used to compare travel patterns among different groups.

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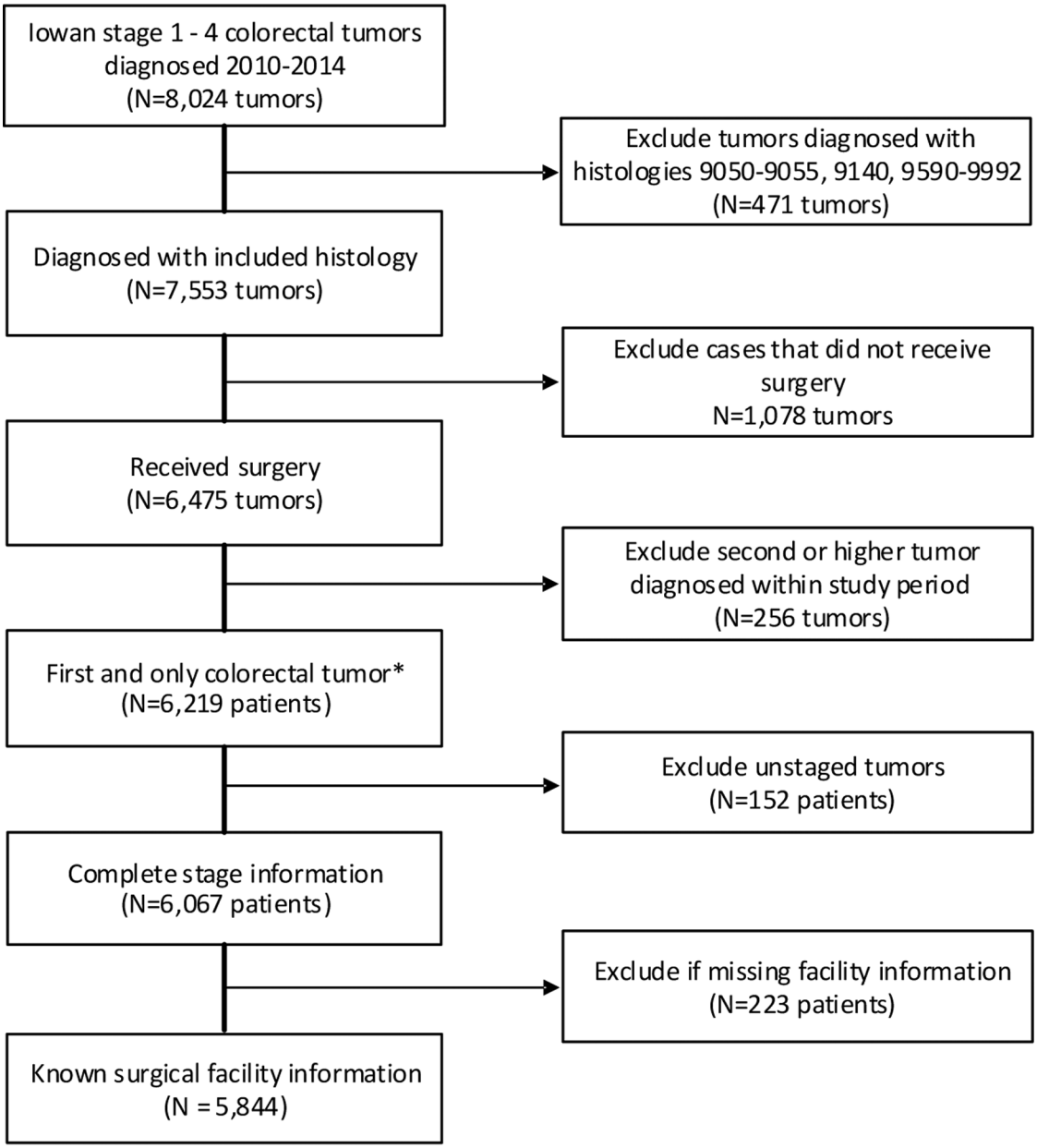

Figure 1:

Flowchart of Inclusion/Exclusion Criteria

*Note: Each observation is a tumor before applying the exclusion criteria because CRC patients can have multiple tumors, but each observation represents a unique patient after excluding the second or higher tumor.

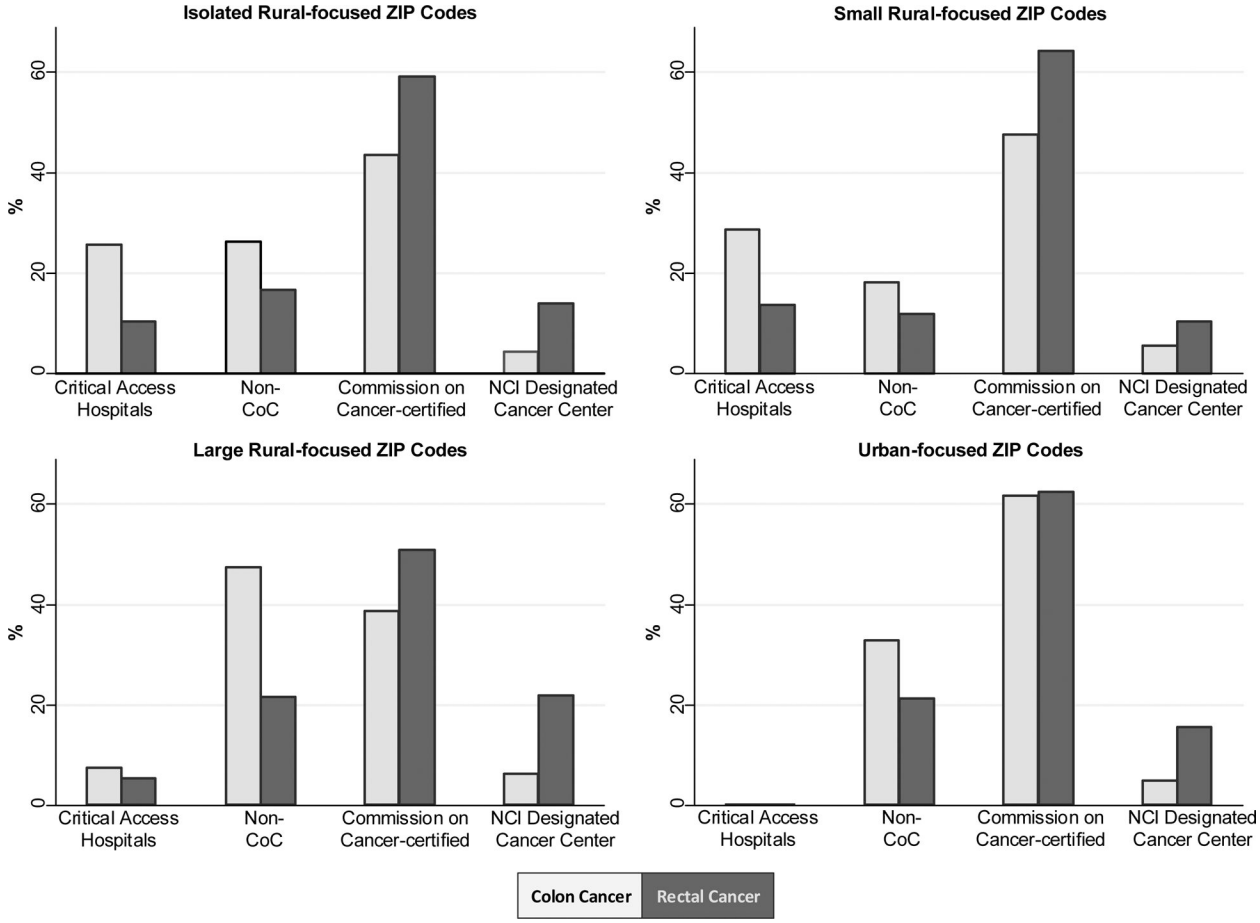

Figure 2:
Actual Surgical Facility Type by Cancer Site and Urban-Rural Designation, Iowa, 2010–2014

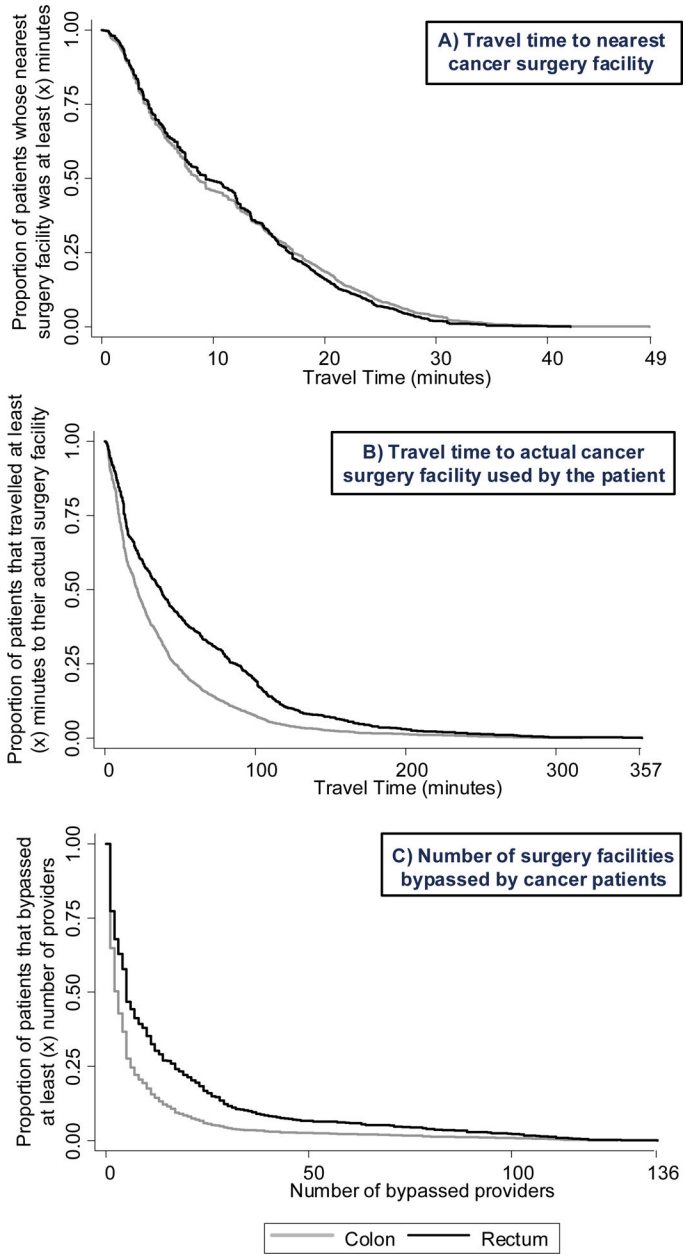

Figure 3:

Kaplan-Meier Curves Showing Differences in A) Travel Time to Nearest Cancer Surgery Facility, B) Travel Time to Actual Cancer Treatment Facility Used by the Patient, and C) the Number of Cancer Surgery Facilities Bypassed, by Colon Versus Rectal Cancer Patients

Table 1:

Characteristics of Hazard Ratios for Time-to-Event Versus Time-to-Place Data

	Time-to-Event Hazard Ratios	**Time-to-Place Hazard Ratios**	**Travel Time Ranks Hazard Ratios**
Initial Condition	Time of diagnosis of a disease	Patient's residential location	Patient's residential location
Duration	Period from diagnosis to death (or end of study)	Travel time from residential location to facilities	Rank: Number of facilities bypassed by patient
Failure	Death	Arrival to facility	Arrival to facility
Censoring	End of Study or Lost to Follow-up	Not applicable in this case study, but censoring could occur if knowledge about travel time was missing	Not applicable in this case study, but censoring could occur if knowledge about travel time was missing
Interpretation of Hazard Ratios (HR)	HR < 1.0: people survived ***longer*** durations than other groups	HR < 1.0: patients had ***longer*** travel times than other groups	HR < 1.0: patients bypassed a ***larger*** number of facilities than other groups
	HR > 1.0: people survived ***shorter*** durations than other groups	HR > 1.0: patients had ***shorter*** travel times than other groups	HR > 1.0: patients bypassed a ***smaller*** number of facilities than other groups

Table 2:

Patient and Tumor Characteristics of Colorectal Cancer Cases Who Received Surgery, Iowa, 2010–2014

		Total		Colon		Rectum		
		N	%	N	%	N	%	*P* value
	Total	5,844		4,765		1,079		
Sex	Male	2,961	50.7	2,308	48.4	653	60.5	< **.0001**
	Female	2,883	49.3	2,457	51.6	426	39.5	
Age at diagnosis	≤64	2,064	35.3	1,447	30.4	617	57.2	< **.0001**
	65–74	1,410	24.1	1,161	24.4	249	23.1	
	≥75	2,370	40.6	2,157	45.3	213	19.7	
Year of diagnosis	2010	1,243	21.3	1,021	21.4	222	20.6	.961
	2011	1,207	20.7	980	20.6	227	21.0	
	2012	1,120	19.2	913	19.2	207	19.2	
	2013	1,107	18.9	897	18.8	210	19.5	
	2014	1,167	20.0	954	20.0	213	19.7	
Histology	Adenomas and adenocarcinomas	5,371	91.9	4,344	91.2	1,027	95.2	< **.0001**
	Cystic, mucinous, and serous neoplasms	473	8.1	421	8.8	52	4.8	
Cancer sequence	First cancer	4,658	79.7	3,747	78.6	911	84.4	< **.0001**
	Second of ≥2 primaries	943	16.1	797	16.7	146	13.5	
	Third of ≥3 primaries	194	3.3	179	3.8	15	1.4	
	Fourth or higher cancer	49	0.8	42	0.9	7	0.7	
AJCC[1] 7th edition stage	Stage I	1,622	27.8	1,263	26.5	359	33.3	< **.0001**
	Stage II	1,817	31.1	1,568	32.9	249	23.1	
	Stage III	1,752	30.0	1,358	28.5	394	36.5	
	Stage IV	653	11.2	576	12.1	77	7.1	
RUCA[2] category of patient	Isolated rural	1,138	19.5	942	19.8	196	18.2	.101
	Small rural	1,138	19.5	932	19.6	206	19.1	
	Large rural	891	15.3	701	14.7	190	17.6	
	Urban	2677	45.8	2,190	46.0	487	45.1	
Facility designation	Critical Access Hospital	621	10.6	560	11.8	61	5.7	< **.0001**
	Commission on Cancer Accredited (CoC)	3,289	56.3	2,598	54.5	691	64.0	
	Non-CoC	1,518	26.0	1,360	28.5	158	14.6	
	NCI-designated Hospital	416	7.1	247	5.2	169	15.7	

Table 3:

Differences in Travel Time to Surgery and Number of Bypassed Facilities for Colon Versus Rectal Cancer by Select Characteristics

	Travel Time to Nearest Cancer Surgery Facility			**Travel Time to Actual Cancer Surgery Facility Used by Patient**			**Number of Cancer Surgery Facilities Bypassed by Patient**		
	Percentiles (minutes)			**Percentiles (minutes)**			**Percentiles (n facilities bypassed)**		
	5th	50th	95th	5th	50th	95th	5th	50th	95th
Total	0.8	9.1	33.8	1.5	22.0	228.5	1	3	33
Colon	0.8	8.9	31.3	1.5	20.2	209.1	1	2	27
Rectal	0.8	9.7	33.8	1.9	37.8	262.3	1	5	71
	Model 1 unadjusted	**Model 7** adjusted[1]	**Model 7**	**Model 1** unadjusted	**Model 7** adjusted[1]	**Model 7**	**Model 1** unadjusted	**Model 7** adjusted[1]	**Model 7**
	HR	HR	Δ minutes	HR	HR	Δ minutes	HR	HR	Δ bypassed
Cancer Site (ref = Colon)									
Rectum	1.056	1.065	< −1	0.643***	0.747***	5.6	0.656***	0.752***	<1
Sex (ref = Female)									
Men		1.018	< 1		1.137***	−3.0		1.108***	<−1
Age (ref = ≥75 years)									
≤64 years		0.926*	< 1		0.763***	5.2		0.802***	<1
65 to 74 years		0.917*	< 1		0.838***	3.6		0.874***	<1
AJCC Stage (ref = Stage I)									
Stage II		1.059	< −1		0.960	<1.0		0.974	<1
Stage III		0.972	< 1		0.981	<1.0		0.976	<1
Stage IV		1.017	< −1		0.943	1.3		0.950**	<1
Rural/Urban Status of Patient (ref = Isolated)									
Small Rural		2.790***	−16.4		1.283***	−6.2		1.048	<−1
Large Rural		2.455***	−13.3		2.104***	−24.3		1.746***	−2.2
Urban		1.837***	−7.7		3.798***	−61.6		2.466***	−4.4
Facility Designation (ref = Commission on Cancer (CoC) Accredited Hospital)									
Critical access hospital		1.229	−2.1		5.386***	−96.4		4.686***	−11.1

	Travel Time to Nearest Cancer Surgery Facility			Travel Time to Actual Cancer Surgery Facility Used by Patient			Number of Cancer Surgery Facilities Bypassed by Patient		
	Percentiles (minutes)			Percentiles (minutes)			Percentiles (n facilities bypassed)		
Non-COC		1.195***	−1.8		0.185***	17.9		1.636***	−1.9
NCI-designated Hospital		0.776***	3.7		0.519***	10.5		0.587***	1.2

[1]American Joint Committee on Cancer;

[2]Rural-Urban Commuting Area

P values from Chi-square test

*$P < .05$,

**$P < .01$,

***$P < .001$

[1]Adjusted for age, sex, stage at diagnosis, urban-rural status of the patient, and facility designation