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A Geographic Analysis Of The Radiation Oncology Workforce: Assessing The Impact On Prostate Cancer Management And Outcomes

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A Geographic Analysis of the Radiation Oncology Workforce: Assessing the Impact on
Prostate Cancer Management and Outcomes

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Abstract

GEOGRAPHIC DISTRIBUTION OF THE RADIATION ONCOLOGY WORKFORCE: IMPLICATIONS ON PROSTATE CANCER.

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Previous analyses of the radiation oncology (RO) workforce have focused on gross numbers and not geographic distribution. We investigated trends in the geographic distribution of the radiation oncology workforce across the United States. Additionally, we assessed the impact of geographic variations in the RO workforce on prostate cancer management and outcomes. We hypothesized that geographic variations in the workforce would be associated with prostate cancer management and prostate-cancer mortality.

We used the Area Resource File to calculate and map the ratio of radiation oncologists to the population aged 65 or older (ROR) within different health service areas (HSA) across the United States from 1995-2007. Multivariate regression models were built to test the association between ROR and socioeconomic variables (income, minority population, unemployment rate, population education). Using patient data from the Surveillance Epidemiology End Results Program (SEER) we built multivariate logistic regression models to test associations between variations in the RO workforce and patient decisions to observe, undergo a radical prostatectomy, or undergo radiation therapy. Using mortality data from the State Cancer Profiles dataset, we built multivariate linear regression to test the association between RO workforce and count-level age-adjusted prostate cancer mortality.

Despite a 24% increase in the workforce from 1995 to 2007, there remained consistent geographic maldistribution of radiation oncologists, specifically affecting the rural HSAs. Regression analysis found higher ROR associated with more educated (p=.001), affluent (p<.001) HSAs with lower unemployment rates (p<.001), and higher minority populations (p=.022). Of the 108,612 prostate cancer patients queried from the SEER dataset, patients with low-risk disease (p<.001) residing in HSAs with fewer radiation oncologists (p=.001-.041), fewer urologists (p<.001), and more primary care physicians (p<.001) were most likely to observed in lieu of curative treatment. Of the 91,643 patients who underwent some form of curative treatment, older, single (p<.001), African American patients (p<.001) with low-risk disease (p<.001) residing in HSAs with more radiation oncologists (p=.007-.001) and primary care physicians (p<.001) were more likely to receive radiation therapy. The presence of at least one radiation oncologist was associated with between 5.74% and 1.48% reduction in prostate cancer mortality (p=.001-.045) even when adjusting for county-level prostate cancer incidence.

Despite a modest growth in the radiation oncology workforce, there exists persistent geographic maldistribution of radiation oncologists allocated along socioeconomic and racial lines. Regional variations in the RO workforce are associated with variations in the management of prostate cancer. The presence of at least one radiation oncologist is associated with a reduction in county-level prostate cancer mortality. There is a need for geographically aware policy in order to optimize the RO workforce and improve prostate cancer outcomes.

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Introduction

The Physician Workforce Crisis

The physician workforce remains the cornerstone to delivering quality healthcare across the United States. Over the last 30 years, population growth has rapidly outpaced commensurate gains in the physician workforce threatening the sustainability of our country's healthcare system.[1] With recent passage of the Patient Protection and Affordable Care Act (ACA), the number of insured Americans is expected to increase by 32 million widening the physician supply gap and increasing the clinical burden on the workforce.[2] The Center for Workforce Studies projects the gap in the physician workforce to increase by 50% by the year 2050. Specifically, the shortage of specialists is expected to quadruple. [3] Because of this known association between access to care and healthcare quality, the ACA attempted to address the physician workforce issue through the establishment of the National Healthcare Workforce Commission, whose sole purpose is to monitor the supply and distribution of physicians. Along with the National Healthcare Workforce Commission, the ACA also established the Center for Medicare and Medicaid Innovation Center whose mission is to optimize the efficiency and quality of care provided by the current physician workforce.[1]

Geography and the Physician Workforce

Despite significant focus on the physician workforce problem, the geographic distribution of the workforce is often overlooked. Previous policy analyses of the physician workforce have primarily focused upon projecting future demand based on gross numbers of physicians.[4,5] Geographic variations on the workforce have been

associated with disparities in health outcomes. Specifically within oncology, geographic access to care has known associations with cancer-related outcomes. Increased urologist density has been shown to be associated with decreased prostate and kidney cancer mortality.[6,7] Dermatologist density has been shown to be associated with reductions in melanoma mortality.[8] Additionally increased density of primary care physicians has been associated with improved cancer specific mortality and all cause mortality.[9] Moreover, geographic proximity to cancer specialists has been associated with variations in the management of breast cancer including surgical choice, and receipt of radiation therapy.[10-13] Whether the current physician workforce is adequately and equitably distributed, to meet and optimize the growing demand for cancer care is an important area of ongoing study.[6,14-16]

The Radiation Oncologist Workforce

The workforce issue is not new to the field of radiation oncology. In 2002 the American Society for Radiology Oncology (ASTRO) Workforce Committee was the first to note shortages in the future of radiation oncology.[17] More recently however, it has been projected that the demand for radiation therapy will increase 10 times faster than the supply for radiation oncologists.[18] The radiation oncology workforce problem has likely exacerbated since ASTRO's first report for at least three reasons. First, technological advancements in the field of radiation oncology have markedly increased the overall demand of radiation therapy to treat cancer despite recent declines in cancer incidence.[18,19] Second, a supply gap has been created by modest increases in the number of training programs in the face of larger increases clinical demands.[18,20] Third, technological advancements in the field that not only increased the quantity of treatment

but also physician planning time have potentially decreased the overall efficiency of the radiation oncologist workforce.[18,21]

Similar to other specialties, previous analyses of the radiation oncology workforce have focused solely on radiation oncologist numbers and projecting the need for the future. Few studies, however, have addressed the geographic distribution of radiation oncologists. Though some disciplines may adapt to a lack of geographic distribution via the use of telemedicine or physician extenders, access to radiation oncology services is particularly dependent on geographic distribution for several reasons. First, a clinical course of radiation therapy requires multiple daily trips for treatment, for up to eight or nine weeks in some cases. Second, given the technical nature of radiation oncology, primary care physicians and physician extenders cannot as readily fill gaps in care caused by lack of radiation oncologists. Third, radiation therapy requires large and immobile equipment that cannot feasibly be transported or quickly erected.[22] Descriptive analysis of the geographic distribution of the radiation oncology workforce is a necessary first step to help inform policy makers and clinicians in ways to best provide radiation therapy and multidisciplinary cancer care.

Treatment of Prostate Cancer across the United States

Prostate cancer is the most common non-cutaneous cancer among men in the Western world. With an estimated 200,000 diagnoses and 30,000 deaths each year, treatment of prostate cancer is of great medical and public significance.[23] [24] Despite its high occurrence rate, the relative 10-year survival rate following treatment of localized prostate cancer is 98%.[23] Though evidence indicates that prostate cancer mortality has

been improving in recent years, the benefit from modern cancer treatment may not be uniform throughout the United States.[25,26] Furthermore, as US population ages, the incidence of prostate cancer is expected to increase dramatically over the next 20 years. In addition to active surveillance, the two most common treatment interventions for patients with localized prostate cancer are prostatectomy and radiation therapy. Although no multi-institutional randomized control trials have compared the two modalities, retrospective studies from the Cleveland Clinic, Memorial Sloan Kettering Cancer Center, and the Joint Center for Radiation Therapy have all found similar biochemical failure rates among both modalities. [27-29] Moreover, despite the different side-effects profiles for each treatment option, recent evidence has found no significant differences in 15-year disease specific functional outcomes when comparing radical prostatectomy and external beam radiation therapy.[30]

Several types of providers are involved in the diagnosis and treatment of prostate cancer. Primary care providers and urologists are typically involved in initial diagnosis whereas urologists, medical oncologists, and radiation oncologists could all potentially be involved in the primary treatment of prostate cancer. Patients are often influenced by counseling physicians when deciding their optimal treatment choice.[31] This is particularly concerning given physicians opinions regarding both treatment modalities vary drastically based on specialty and geographic region.[31] The influence the distribution of radiation oncologists, urologist and primary care providers on the management of prostate cancer remains unclear.

Furthermore, the relative impact of the distribution of radiation oncologists, urologists, and primary care providers on prostate cancer mortality is unknown. As

radiation oncologists also serve as primary treatment providers for prostate cancer, the association between the availability of radiation oncologists and prostate cancer mortality merits exploration.

It is likely that variation in the geographic distribution of radiation oncologists is related to the receipt of cancer treatment and outcomes, particularly for those patients who are not candidates for surgery. Alternatively, patients who are surgical candidates, but refuse surgery, may choose radiation therapy as an alternative curative treatment if a radiation oncologist is geographically accessible. External beam radiotherapy, the dominant form of radiation treatment in the US, typically requires multiple daily radiation treatments for 6-9 weeks, making the geographic distribution of radiation oncologists more important, particularly for patients with limited mobility and resources for travel. As it is known that travel time to the nearest cancer center varies significantly throughout the country, inequities in geographic access may be associated with variations in cancer mortality.[32]

To investigate these issues, we studied trends in the geographic distribution of the radiation oncology workforce across the United States. Additionally, we studied the association between geographic variations in the radiation oncology workforce and regional prostate cancer management and mortality. We hypothesized that there existed geographic variations in the radiation oncology workforce that were associated with differences in the treatment choices of prostate cancer patients as well as prostate cancer mortality.

Project Aims

1. To evaluation trends in the geographic distribution of the radiation oncology workforce from 1995 to 2007.

2. To compare the trends in geographic distribution of the radiation oncology workforce to the primary care physician and total physician workforces from 1995 to 2007.

3. To identify population and geographic factors associated with the distribution of the radiation oncologists in 2007.

4. To evaluate associations between geographic variations in the radiation oncology workforce and patient prostate cancer treatment choice from 2004 to 2007

5. To evaluate associations between geographic variations in the radiation oncology workforce and regional prostate-cancer mortality rates from 2003 to 2007.

Hypothesis

We expect to find significant geographic variations in the radiation oncology workforce that have persisted from 1995 to 2007. We also expect to find an association between regional variations in the radiation oncology workforce and the management of prostate cancer. Specifically, we expect regions with higher densities of radiation oncologists to have lower rates of surveillance and higher rates of radiation therapy treatment. Finally, we expect regions with higher densities of radiation oncologists to be associated with lower prostate cancer mortality rates.

Methods

Data Sources

This study utilized three publically available data sources. The Area Resource File provided regional demographic, population, and physician distribution data.[33,34] The Surveillance Epidemiology End Results Public-Use Dataset provided clinical, demographic, and treatment data for patients diagnosed with prostate cancer.[34] Finally, the State Cancer Profiles Dataset provided regional prostate cancer specific mortality data.[35]

The Area Resource File

Using the 1995 and 2007 editions of the Area Resource File (ARF), we obtained demographic, population, and physician distribution data.[33] Published by the Health Resources and Services Administration of the US Department of Health and Human Services, the ARF is a collection of data from over 50 sources, including the American Medical Association, American Hospitalization Association, US Census, and National Center for US Health Statistics. The ARF aggregates information concerning the healthcare professionals, healthcare facilities, and population for each county in the United States. Specifically, the ARF includes the number of specialists within each county based on data from the American Medical Association (AMA) Physician Masterfile.

The Surveillance Epidemiology End Results Public-Use Dataset

We obtained patient linked prostate cancer treatment choice data from the Surveillance Epidemiology End Results (SEER) Public-Use Dataset. The SEER Public-Use Dataset provided demographic staging, pathologic findings, extent of surgery, and receipt of radiation therapy for patients treated with prostate cancer for the years 2004 through 2007. Originally established in 1973 by the National Cancer Institute (NCI) the SEER Public-Use Dataset is an aggregate of population-based cancer registries across the United States. The SEER Public-Use Dataset comprises approximately 26% of the United States. The following state and individual population-based registries were included our analysis: Alaska Native Tumor Registry, Arizona Indians, Cherokee Nation, Connecticut, Detroit, Georgia Center for Cancer Statistics, Atlanta, Greater Georgia, Rural Georgia, Greater Bay Area Cancer Registry, San Francisco-Oakland, San Jose-Monterey, Greater California, Hawaii, Iowa, Kentucky, Los Angeles, Louisiana, New Jersey, New Mexico, Seattle-Puget Sound, Utah.[34,36]

The State Cancer Profiles Dataset

County level prostate cancer specific mortality and incidence data was obtained from the State Cancer Profiles Dataset. The State Cancer Profiles Dataset is a merged dataset from the NCI SEER program, National Program for Cancer Registries (NPCR), and United States Center for Disease Control and Prevention's National Vital Statistics System.[35] Prostate cancer specific mortality and incidence data were reported as age-adjusted average rates per 100,000 people from the years 2003 to 2007. Cancer incidences and mortalities were assigned to counties based on patient residence at the time of diagnosis and death, respectively.

Geographic Units of Analysis

National Cancer Institute Health Service Areas

When evaluating trends in the geographic distribution of the radiation oncology workforce and the influence of geographic variations on prostate cancer treatment choice the geographic units of analysis were the 950 Health Service Areas (HSAs) within the United States as defined by the National Cancer Institute. HSAs are defined as a single county or group of contiguous counties that remain self-contained with respect to hospital care.[16] HSAs were chosen as the unit of analysis because they best represent geographic access to healthcare within a region. County level data from the ARF was aggregated to HSAs using simple summation for physician and population variables and population weighted sums descriptive variables. Patients within the SEER Public-Use Dataset were assigned HSAs based on county-specific FIPS codes assigned to the patient based on residence. The data from the SEER Public-Use Dataset contained data for patients located in 170 HSAs comprising approximately 17.9% of the United States.

United States Counties

When evaluating the association between geographic variations in the radiation oncology workforce and regional prostate cancer specific mortality the geographic units of analysis were the 3,141 counties in the United States as defined by the 2000 Census. Counties were specifically chosen for analysis of regional prostate cancer specific mortality because the State Cancer Profiles dataset that could not be accurately aggregated to HSAs. Similar to previous studies investigating the impact of physician density on cancer-related mortality, rural counties were excluded from the analysis

because only 0.4% of the 669 rural counties in the United States possessed radiation oncologists and many of them lacked complete mortality data.[6,8] Following exclusion of rural counties, 2,472 non-rural counties comprising approximately 78.7% of the United States possessed complete mortality data and were available for analysis. Counties were classified as rural based on 2003 Department of Agriculture Rural/Urban Continuum Codes.

Trends in the Geographic Distribution of the Radiation Oncology Workforce

To evaluate the geographic distribution of radiation oncologists across the United States the primary outcome was the ratio of radiation oncologists to population aged 65 or older (ROR). The physician to population ratio remains a frequently used measure of physician distribution within a region. [6,37] The elderly were chosen as the population of interest because they represent a group that has the highest prevalence of cancer and represent a demographic which utilizes a significant portion of healthcare services in the United States. [18,38] In addition, elderly patients may be less mobile than younger patients, and may be more hesitant to travel long distances for their care meaning geographic proximity is of utmost importance. The ROR of each HSA was calculated as the number of radiation oncologists per 100,000 people aged 65 or older. RORs for each HSA were generated for the years 1995 and 2007. To compare the distribution of radiation oncologists to other physician specialties, equivalent ratios were calculated for the primary care physician (PCPR) and total physician (MDR) workforces. PCPs were defined as physicians in general practice, family practice, or general internal medicine. Population aged 65 or older estimates and physician workforce estimates were obtained from the ARF.

To evaluate changes in the distribution of the workforce, mean RORs were calculated for 1995 and 2007 and compared with equivalent changes in PCPR and MDR. To assess the current distribution of radiation oncologists, each HSA was ranked based on ROR and compared to equivalent rankings of PCPRs and MDRs. In an effort to visually compare the distribution of radiation oncologists between different HSAs and trends in their distribution, ROR values were mapped to corresponding HSAs.

Lorenz Curves and Gini Coefficients

Traditionally used to assess distribution of wealth, Gini coefficients and Lorenz curves have recently been used to evaluate physician distribution. [37,39,40] The Lorenz curve was constructed by graphing the cumulative percentage of radiation oncologists as ranked by RORs versus the cumulative percentage of the population age 65 or older. A 45° line representing a perfectly even distribution was drawn from the origin to the maximum point of the Lorenz curve. The Gini coefficient was calculated by dividing the area between the Lorenz curve and the 45° line by the total area under the 45° line. The Gini coefficient ranges in value from 0 (complete equity) to 1 (complete inequity) and serves as a quantitative way to describe relative 'evenness' of physician distribution. Because Gini coefficients possess a linear relationship, changes in value can be used to evaluate changes in the evenness of physician distributions over time. Lorenz curves and Gini coefficients were generated to examine the radiation oncologist distribution among all HSAs between 1995 and 2007. Subgroup analysis was performed to compare the evenness of radiation oncologist distribution, specifically in less populated HSAs, using population quartiles. To assess the uniqueness of the radiation oncologist distribution

compared to all other physicians and PCPs, Lorenz curves and Gini coefficients were also calculated for all physicians and PCPs between 1995 and 2007.

Negative Binomial Regression Analysis

To evaluate population characteristics potentially associated with the current geographic distribution of radiation oncologists, regression analysis was used. After assessing distribution, mean, and variance of HSA-level ROR, zero-inflated negative binomial regression was chosen. The dependent variable was ROR for the year 2007. The independent variables included county level population race, income, education, and unemployment rate obtained from the ARF that were aggregated to HSA level using weighted sums. Population race was defined as percentage white population within each HSA from the 2000 Census. Population income was defined as the median household income according to the 2007 Census update. Population education was defined as percentage population age 25 or older with at least a high school education according to the 2000 Census. Finally, unemployment rates for each HSA were from the 2007 Bureau of Labor Statistics estimates. Independent multivariate regression models were built using backwards-stepwise selection with a univariate $p<.15$ for inclusion into the model. A Vuong test was used to assess the appropriateness of the model. Statistical significance was determined at $p<.05$.

Radiation Oncologist Distribution and Prostate Cancer Management

To evaluate whether variations in the distribution of radiation oncologists was associated patient decisions to undergo treatment for prostate cancer, prostate cancer treatment and patient data were obtained from the SEER Public-Use dataset and merged

with physician workforce and socioeconomic data from the ARF for the years 2004

through 2007. Each prostate cancer patient within the registry was assigned physician

workforce densities and socioeconomic data based on their HSA of residence. In addition

to radiation oncologist densities, primary care physician and urologist densities were also

obtained because of their previously described influence on prostate cancer screening and

treatment outcomes.[6,31] Densities were reported per 100,000 residents using 4-year (2004-

2007) population averages based on US Census estimates. To examine if incremental

changes in radiation oncologist density accompany changes in the management of

prostate cancer, radiation oncologist densities were categorized (0, 0.1 to 1.0, 1.1 to 2, 2.1

to 3.0, >3.0 per 100,000 people). Socioeconomic variables of interest included

population income, unemployment rates, and population education. The socioeconomic

data were obtained from the ARF and aggregated as stated above.

Because appropriate prostate cancer intervention varies based on aggressiveness

of disease patients were classified into low, intermediate and high-risk categories based

on NCCN criteria.[41] Patients were defined as 'low-risk' if their prostate cancer was

Gleason 6, possessed a PSA < 10.0, and staged T1cN0M0. Patients were defined as

'high-risk' if their prostate cancer was Gleason 8-10, presented with a PSA > 20.0, or

staged T3N0M0. Individual patient characteristics were obtained from the SEER-Public

Use data and included in the analysis. Patient characteristics of interest were patient race,

age, and marital status. Treatment choice data obtained from the SEER Public-Use

Dataset and were defined as 'observation' or 'attempted curative therapy'. Attempted

curative therapy consisted of a radical prostatectomy, radiation therapy (External-Beam

Radiation Therapy and brachytherapy) or combination surgical and radiation therapy treatment.

Logistic Regression Analysis

A primary logistic regression model was built for the entire cohort to evaluate the association between radiation oncologist density and observation of prostate cancer. For patients who attempted curative therapy, two additional logistic models were built to test the association between radiation oncologist densities and the type of curative therapy chosen. The primary outcome variables for these additional models were receipt of a radical prostatectomy and receipt of radiation therapy respectively. Independent multivariate regression models using the above covariates were built using backwards-stepwise selection with a univariate p<.15 for inclusion into the multivariate model. Statistical significance was determined at p<.05.

Radiation Oncologist Distribution and Prostate Cancer Mortality

To evaluate whether regional variations in the radiation oncologist workforce impacted prostate cancer outcomes, physician workforce and socioeconomic data from the ARF was combined with county-level prostate cancer specific mortality data from the State Cancer Profiles Dataset for the years 2003 through 2007. Socioeconomic variables of interest included population income, unemployment rates, and population education as defined above. To account for geographic variations patient populations, percent population Caucasian, percent population aged 65 or older based on the Census County File were also included in the analysis.

In addition to radiation oncologist density, urologist and primary care physician densities were analyzed. In an effort to assess if reductions in prostate cancer mortality were related to non-specific specialists, a non-oncology specialty, Allergy-Immunology, was chosen as a control variable to test whether changes in cancer mortality were more specifically attributed to radiation oncologist density. Allergists-Immunologists were chosen a priori as an ideal comparison specialist because they have no known associations to prostate cancer management and possess a workforce size and geographic distribution similar to that of radiation oncology. Physician densities were calculated as five-year means (2003 to 2007) of physicians per 100,000 people using annual Census county population estimates.

Prostate cancer specific mortality data from the State Cancer Profiles data were reported as county-level age-adjusted average rates per 100,000 people from the years 2003 to 2007. In an effort to better examine if incremental changes in radiation oncologist density accompany changes in prostate cancer mortality, radiation oncologist densities were categorized (0, 0.1 to 1.0, 1.1 to 2, 2.1 to 4.0, >4.0 per 100,000 people). To account for potential geographic variations in prostate cancer screening, prostate cancer incidence among counties in the United States was also included in the model. Cancer incidences and mortalities were calculated for each county based on each a patient's residence at the time of diagnosis and death, respectively.

Linear Regression Analysis

A linear regression model was built with prostate cancer mortality per 100,000 people as the primary outcome variable. Univariate associations between physician

workforce, health system, and socioeconomic predictor variables and cancer mortality were calculated using t tests for categorical variables and linear regression for continuous variables. The multivariate model were built using backward stepwise selection with a univariate $p<0.15$ for inclusion into the model. Allergist-Immunologist density was manually inserted into the final model to control for changes in cancer mortality that could potentially be attributed to a high overall specialist density. Statistically insignificant Allergist-Immunologist density in the final model would suggest changes in cancer mortality were likely unattributed to high overall specialist density. Statistical significance for the final models was determined at $p<0.05$. Variance inflation factors were used to control for excessive collinearity amongst variables. Percent changes in mortality were calculated for each density category using the cancer mortality of a reference group. The reference group in all three models was a county with no radiation oncologists, urologists or allergists. To evaluate incremental benefits derived from increasing radiation oncologist density beyond the reference group, linear combination estimates were calculated comparing radiation oncologists among different density categories.

Statistical analysis was conducted using SAS Version 9.2 (SAS, Cary, NC) and Stata Version 9.2 (Stata, College Station, TX). Mapping of data was done using the geographical information system ArcGIS Version 9.2 (Environmental Systems Research Institute, Inc., Redlands, CA). Transformation of data between geographic units was done using a combination of ArcGIS Version 9.2 (Environmental Systems Research Institute, Inc., Redlands, CA), SAS Version 9.2 (SAS, Cary, NC) and Stata Version 9.2 (Stata,

College Station, TX). All data transformation, statistical analysis, and map creation was completed independently by Sanjay Aneja, BS and overseen by James B. Yu, MD.

Results

Trends in the Geographic Distribution of the Radiation Oncology Workforce

In the twelve-year period of our study, the radiation oncology workforce grew approximately 24%, from 3,515 radiation oncologists in 1995 to 4,378 in 2007. Over the same time period, the PCP workforce grew approximately 31%, from 213,619 physicians to 278,728. Similarly, the overall physician workforce grew 29%, from 617,362 physicians to 794,184. The mean ROR increased by slightly more than one radiation oncologist per 100,000 people. **(Table 1)** In contrast, mean PCPR and MDR increased by 85 physicians per 100,000 people and 145 physicians per 100,000 people, respectively. Increases in the mean ROR, although modest, suggest a growth in the radiation oncology workforce that outpaced the growth of the elderly population.

Table 1: Mean Physician to Population Aged 65 or Older Ratio: 1995 and 2007

	1995	2007	% Change
Radiation Oncologists per 100,000	5.08	6.16	21.26
PCP per 100,000	521.67	606.50	16.26
MD per 100,000	1056.44	1201.35	13.72

The distribution of radiation oncologists was significantly more skewed than PCPs and MDs. In the year 2007, approximately 44% of HSAs within the United States

lacked a radiation oncologist. Comparatively, approximately .74% of HSAs lacked a PCP and .63% lacked a physician of any kind. Moreover, approximately 75% of HSAs had two or fewer radiation oncologists per 100,000 people aged 65 or older. Additionally, there existed consistent geographic maldistribution of radiation oncologists from 1995 to 2007. **(Figure 1)** HSAs within the Northeast, California, and Florida exhibited high RORs in both 1995 and 2007, whereas rural HSAs within the Midwest generally exhibited lower RORs in 1995 and 2007 relative to the rest of the country. **(Figure 2)**

Figure 1: Distribution of Radiation Oncologists Among Health Service Areas: 1995, 2007

Distribution of Radiation Oncologists: 1995

Distribution of Radiation Oncologists: 2007

1 Dot = 1
Radiation Oncologists
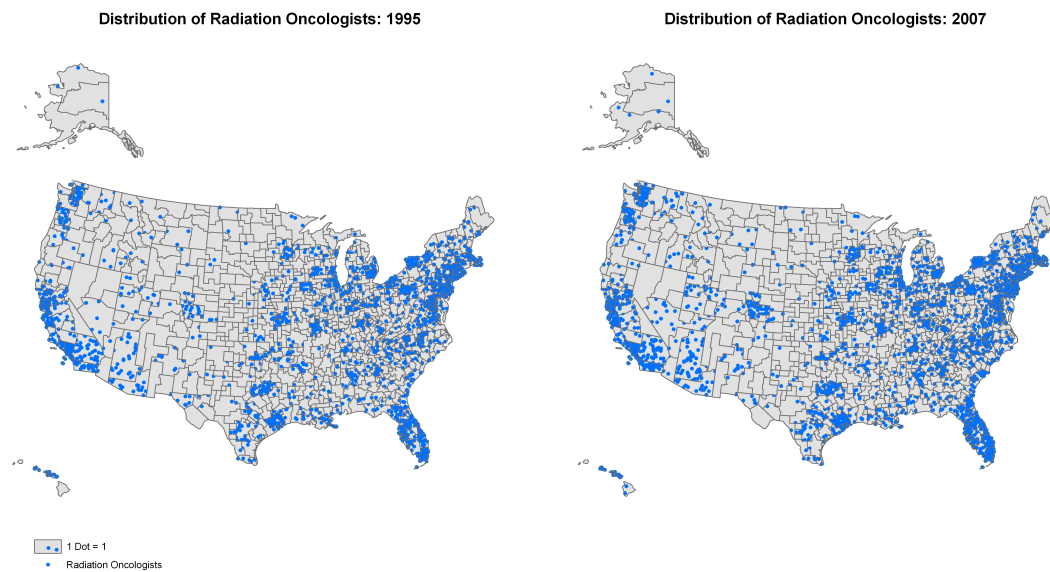
Figure 2: Ratios of Radiation Oncologists to Population Aged 65 or Older Among Health Service Areas: 1995, 2007

Ratios of Radiation Oncologists to Population Aged 65 or Older: 1995   Ratios of Radiation Oncologists to Population Aged 65 or Older: 2007

0 per 100,000   6-8 per 100,000
<2 per 100,000   8-10 per 100,000
2-4 per 100,000   10-12 per 100,000
4-6 per 100,000   >12 per 100,000
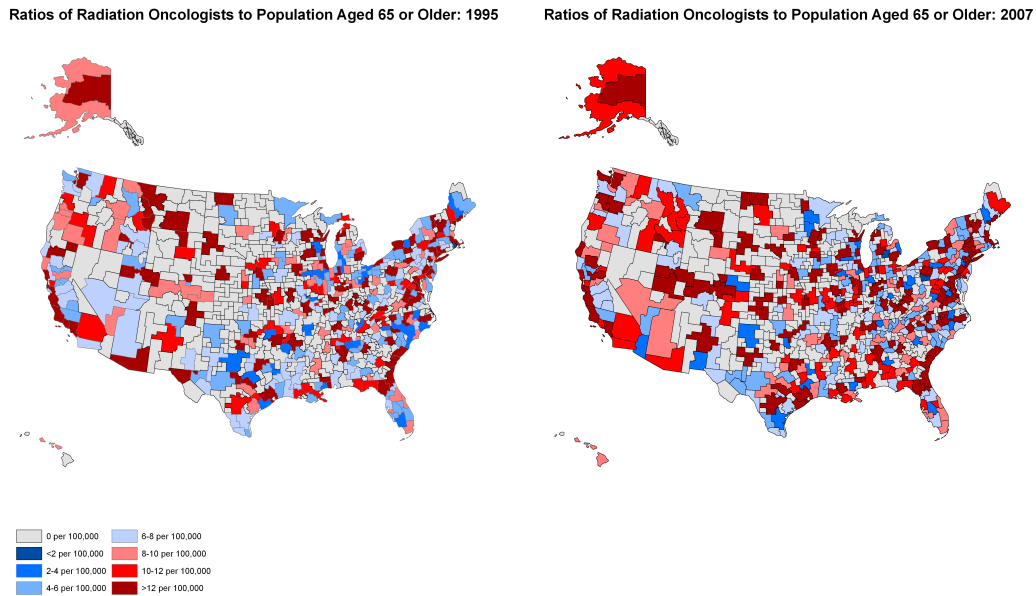
Equitable Distribution of the Radiation Oncologist Workforce

Gini coefficient calculations confirmed the maldistribution of the radiation oncology workforce. Radiation oncologists were less evenly distributed than both PCPs and MDs in both 1995 and 2007. **(Table 2)** However, the Gini coefficients of all three groups exhibited a percentage decrease, indicating an improvement in distribution towards equity. Radiation oncologists exhibited the largest change (-10.93%), followed by PCPs (-4.85%) and finally MDs (-2.34%). Analysis of Gini coefficients within population quartiles highlighted the uneven distribution of radiation oncologists in non-metropolitan areas. Specifically we found that, unlike PCPs and MDs who possessed

relatively similar Gini coefficients among different population quartiles, the Gini coefficient of radiation oncologists in the lowest population quartile was an inequitable .951, compared to .251 in the highest population quartile. **(Table 3)** The difference between Gini coefficients among population quartiles suggests the geographic maldistribution of radiation oncologists stems primarily from inequity in less populated non-metropolitan HSAs.

Table 2: Trends Gini Coefficients Among Different Physicians, 1995-2007

	1995	2007	Change	% Change
Radiation Oncologists	0.366	0.326	-0.040	-10.93
PCP	0.206	0.196	-0.010	-4.85
MD	0.299	0.292	-0.007	-2.34

Table 3: Gini Coefficients Among Population Quartiles, 2007

	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Radiation Oncologists	0.951	0.675	0.402	0.251
PCP	0.268	0.233	0.232	0.169
MD	0.333	0.258	0.265	0.236

Factors Associated with Radiation Oncologist Distribution

Regression analysis found an association between radiation oncologist distribution and population characteristics. Univariate Zero Inflated Negative Binomial Regression showed that increased ROR in 2007 was associated with HSAs with lower unemployment rates (p<.001), higher household incomes (p<.001), and higher education

rates (p=.001). **(Table 4)** Surprisingly, decreased ROR in 2007 was associated with HSAs that had higher percent white population (p=.022). Multivariate analysis confirmed the association between increased ROR and lower unemployment rates (p<.001), higher household incomes (p<.001), and increased minority population (p=.010). Higher education rates proved to be insignificant in the multivariate model (p= .461). Because the association between minority population and ROR was unexpected, a separate model using percent African American population was built to confirm the association with minority groups. The confirmatory model yielded similar results (p<.001).

Table 4: Socioeconomic Factors Associated with ROR: 2007

Independent Variable	Univariate				Multivariate			
	Incidence Rate Ratio	p	95% CI		Incidence Rate Ratio	p	95% CI	
Percent White Population	.995	.022	.992	.999	.995	.010	.991	.978
Unemployment Rate	.889	<.001	.858	.921	.906	<.001	.872	.891
Percent High School Education	1.01	.001	1.00	1.02	1.01	.461	.999	1.02
Median Household Income (in $10K)	1.01	<.001	1.00	1.02	1.01	<.001	1.00	1.02

Radiation Oncologist Distribution and Prostate Cancer Management

We isolated 108,613 prostate cancer patients from the SEER Public-Use Dataset. 16,969 (15.6%) patients opted for active surveillance of their prostate cancer. **(Table 5)**

47,484 (43.7%) of patients underwent some form of radiation therapy and 45,367 (41,8%) underwent radical prostatectomy. Single (p<.001), older (p<.001), African American (p<.001) patients with low-risk disease (p<.001) residing in HSAs with fewer radiation oncologists (p=.001-.041), fewer urologists (p<.001), and more primary care physicians (p<.001) were most likely to pursue active surveillance. **(Table 6)** Of the 91,643 (84.38%) of patients who underwent some form of curative treatment, older, single (p<.001), African American patients (p<.001) with low-risk disease (p<.001) residing in HSAs with more radiation oncologists (p=.007-.001) and primary care physicians (p<.001) were more likely to some form of receive radiation therapy. **(Table 7)** Conversely, married (p<.001), white (p<.001), younger (p<.001) patients with higher risk disease (p<.001) living in HSAs with fewer radiation oncologists (p=.006-.001), more urologists (p<.001) and fewer primary care physicians (p<.001) were likely to receive a radical prostatectomy. Incremental increases in radiation oncologist density were associated with commiserate decreases likelihood of surgical treatment and observation.

Table 5: Prostate Cancer Patients: SEER Public-Use Dataset 2004-2007

	N	%
Total	108,613	100.0%
Treatment Choice		
Observation	16,969	15.6%
Radiation Therapy	47,484	43.7%
Radical Prostatectomy	45,367	41.8%
Race		
White	88,898	81.8%
African American	13,586	12.5%
Other	6,058	5.6%
Married	85,106	78.4%
NCCN Risk Group		
Low Risk	30,782	28.3%
Intermediate Risk	61,863	57.0%
High Risk	15,967	14.7%
	Median	
Age	65	
Radiation Oncologists Per 100,000	1.44	
Urologists Per 100,000	3.29	
PCP Per 100,000	66.69	

Table 6: Predictors of Active Surveillance of Prostate Cancer: 2004 to 2007

	Observation			
	Odds Ratio	P	95% CI	
Radiation Oncologists per 100,000				
>0-1.0 v 0	.895	.030	.810	.989
>1.0-2.0 v 0	.856	.001	.847	.864
>2.0-3.0 v 0	.845	.002	.758	.942
>3.0 v 0	.851	.041	.730	.994
Urologists per 100,000	.920	<.001	.902	.939
PCPs per 100,000	1.005	<.001	1.004	1.007
Age	1.097	<.001	1.094	1.099
Race				
African American v White	1.621	<.001	1.540	1.706
Other v White	.878	.001	.814	.947
Married	0.632	<.001	0.608	0.658
NCCN Risk Group				
Intermediate v Low	0.607	<.001	0.584	0.632
High v Low	0.765	<.001	0.726	0.806

Table 7: Predictors of Prostate Cancer Treatment Interventions: 2004 to 2007

	Radical Prostatectomy				Radiation Therapy			
	Odds Ratio	P	95% CI		Odds Ratio	P	95% CI	
Radiation Oncologists per 100,000								
>0-1.0 v 0	.886	.006	0.813	.967	1.125	.007	1.033	1.226
>1.0-2.0 v 0	.832	<.001	0.825	.839	1.194	.001	1.062	1.326
>2.0-3.0 v 0	.814	<.001	0.741	.894	1.261	<.001	1.149	1.383
>3.0 v 0	.729	<.001	0.638	.833	1.370	<.001	1.201	1.563
Urologists per 100,000	1.129	<.001	1.084	1.173	0.985	.071	.968	1.001
PCPs per 100,000	.995	<.001	0.994	.997	1.005	<.001	1.004	1.006
Age	.877	<.001	0.875	.879	1.125	<.001	1.123	1.128
Race								
African American v White	.545	<.001	.520	.571	1.779	<.001	1.698	1.863
Other v White	.912	.006	.854	.974	1.154	<.001	1.081	1.232
Married	1.517	<.001	1.461	1.574	0.690	<.001	0.665	0.716
NCCN Risk Group								
Intermediate v Low	2.010	<.001	1.943	2.080	0.534	<.001	0.516	0.552
High v Low	1.388	<.001	1.320	1.458	1.009	0.711	0.961	1.061

Radiation Oncologist Distribution and Prostate Cancer Mortality

Similar to HSAs the radiation oncologist was heterogeneously distributed among counties in the United States, with 1,616 (65.3%) counties lacking the presence of any radiation oncologists. **(Figure 3)** Of the 2,472 counties studied 1205 (48.7%) were without the presence of both a radiation oncologist and urologist. The mean radiation oncology and urologist densities among counties were .65 and 2.00 per 100,000 respectively. The baseline prostate cancer mortality in a county without the presence of a radiation oncologist, urologist, or allergist was 38.68 deaths per 100,000 people (95% CI

33.94-43.42). The presence of a radiation oncologist was associated with a statistically significant reduction in prostate cancer mortality, despite adjusting for variations in urologist and allergist/immunologist density, as well as socioeconomic, demographic and health system characteristics **(Table 8).** Compared to counties without radiation oncologists, having >0-1, 1-2, or 2-4 radiation oncologists per 100,000 people significantly reduced prostate cancer specific mortality by -3.65% (p=0.031), 5.74% (p<0.001), and 1.48% (p=0.045), respectively. The prostate cancer specific mortality of patients residing in a county with 4 or more radiation oncologists per 100,000 people was not significantly different from counties where there were no radiation oncologists (p=.769). The confidence intervals of this group were wide, given the small number of counties with 4 or more radiation oncologists per 100,000 residents. **(Figure 4)** Linear combination estimates found increasing radiation oncologist density beyond 1.0 per 100,000 provided no statistically significant incremental reductions in prostate cancer mortality compared to having 0.1-1.0 radiation oncologists per 100,000. **(Table 9)**

Figure 3: Distributions of Radiation Oncologists and Urologists Among US Counties
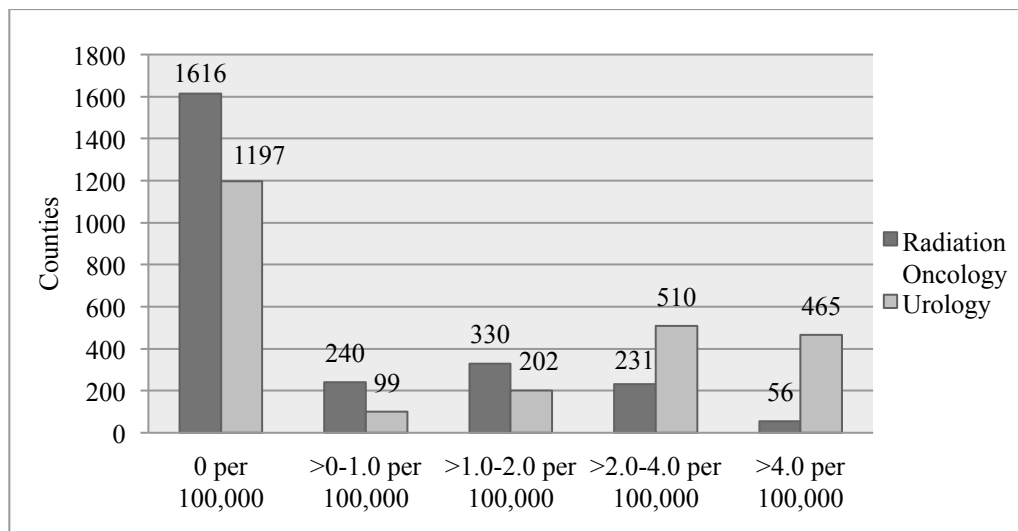
Figure 4: Reduction in Prostate Cancer Mortality for a Given Radiation Oncologist Density
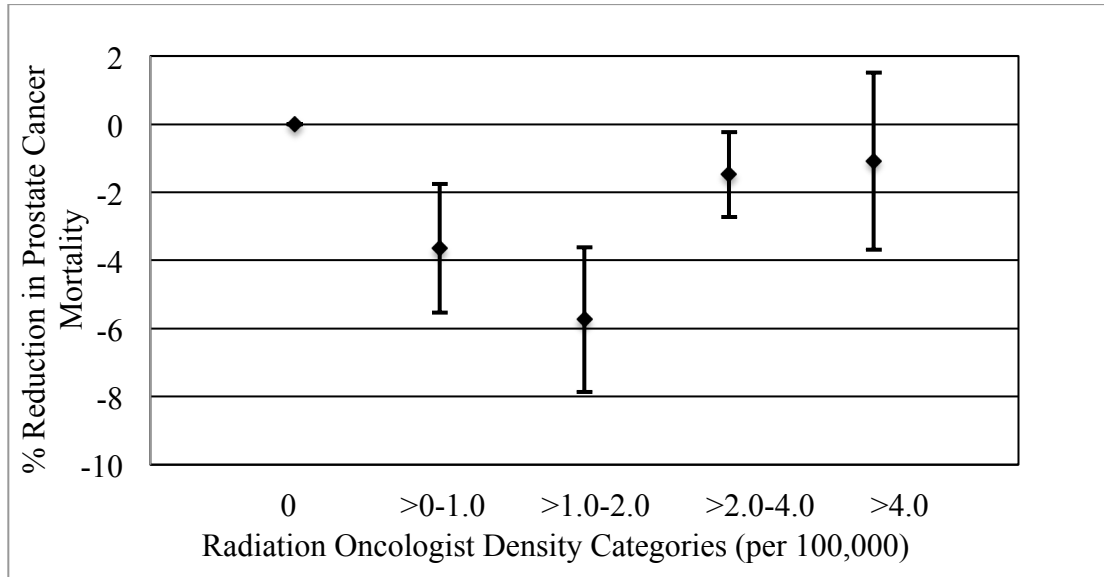
Table 8: Predictors of County Level Prostate Cancer Mortality: 2003-2007

	% Change in Prostate Cancer Mortality	P	95% CI	
Radiation Oncologists per 100,000 People				
>0-1.0 v 0	-3.65	.031	-5.54	-1.76
>1.0-2.0 v 0	-5.74	<.001	-7.87	-3.61
>2.0-4.0 v 0	-1.48	.045	-2.73	-0.23
>4.0 v 0	-1.09	.769	-3.69	1.51
Urologists per 100,000 People	-12.63	<.001	-16.43	-6.60
Allergist Immunologists per 100,000 People	-0.59	.340	-1.80	0.62
Percent Population Aged 65 or Older	1.23	.001	0.51	1.94
Median Household Income (in $10,000)	-2.97	<.001	-4.17	-1.76
Percent Population with High school Education	-0.17	<.001	-0.01	-5.14
Percent White Population	-0.39	<.001	-0.47	-0.31
Prostate Cancer Incidence	0.05	.007	0.01	0.09
	Prostate cancer deaths per 100,000 people		95% CI	
Reference Group: Prostate Cancer Mortality in a county with no radiation oncologists, urologists or allergists	38.68		33.94	43.42

*Note: Primary care physician density, and unemployment rate either did not meet univariate inclusion criteria or were not statistically significant in multivariate model.

Table 9: Incremental Benefit of Increasing Radiation Oncologist Density on Prostate Cancer Mortality

	Prostate Cancer Mortality		
Radiation Oncology Density Categories	% Change in Mortality	P	OR
1.1-2.0 v 0.1-1.0	-2.1	0.221	0.45
2.1-4.0 v 1.1-2.0	4.3	.190	1.81
>4.0 v 2.1-4.0	0.4	.912	1.16

Consistent with previous studies, increasing density of urologists also was associated with a reduction in prostate cancer mortality (p<.001). Allergist/Immunologist density was not related to prostate cancer mortality (p=0.340). Residing in a more affluent county with a younger and more educated population was correlated with reduced prostate cancer mortality **(Table 8)**. Moreover, racial makeup of counties was found to be associated with variations in prostate cancer mortality. Counties with higher percentages of Caucasians were associated with reduction in prostate cancer mortality (p<.001). Primary care physician density and county unemployment rate were both not significant in the multivariate model.

Discussion

This study serves as one of the first comprehensive geographic analyses of the radiation oncology workforce. We found that despite a modest growth in the radiation oncology workforce over the 12 years there remained a persistent geographic maldistribution of radiation oncologists across the United States. The uneven distribution of radiation oncologists is associated with socioeconomic characteristics and most

profoundly seen in rural regions. Moreover, the growth in the radiation oncology workforce over the 12 years did not match the growth of the overall physician workforce and primary care workforces during the same period of time. Furthermore, geographic variations in the workforce were associated with regional variations in the management of prostate cancer. Finally and arguably most concerning, we found an association between geographic variations in the radiation oncologist workforce and county-level prostate cancer outcomes with regions lacking radiation oncologists having increased prostate cancer specific mortality rates even when adjusted for variations in prostate cancer incidence. Our study suggests that the physician workforce problem should not merely focus on physician numbers but also the geographic distribution of physicians.

The growth in the radiation oncology workforce was modest compared to the overall growth in the physician workforce. The radiation oncology workforce grew 5% less than the overall physician workforce and 9% less than the primary care workforce. In a 12-year period, the mean ROR increased by slightly more than one radiation oncologist per 100,000 people aged 65 or older compared to larger increases in the PCPR and MDRs. The modest growth in the radiation oncology workforce is most likely due to increasing residency positions for radiation oncology.[42-44]

Despite growth in the workforce, there was persistent geographic variation in the distribution of radiation oncologists in 1995 and 2007. Mapping of the RORs for 1995 and 2007 showed large geographic segments of the elderly population having little or no access to radiation therapy services, specifically in non-metropolitan areas. In 2007, an alarming 44% of HSAs in the United States lacked radiation oncologists. This translated to 3,137,580 people aged 65 or older without access to radiation therapy in their HSA.

Comparatively, Gini analysis showed radiation oncologists were less evenly distributed than both PCPs and the overall physician workforce. Our finding that PCPs were the most evenly distributed replicates findings from previous studies and suggests that recent policy initiatives to increase geographic access to primary care have been successful. [37,45] More interestingly, the main driver in the uneven geographic distribution of radiation oncologists was an inequitable distribution in less populated non-metropolitan HSAs. The lack of access to radiation oncologists in less populated non-metropolitan areas is perhaps due to the large capital investment required to obtain the equipment and resources necessary to establish a radiation oncology practice. These impediments are increased in rural areas where patient population levels are potentially less. Conversely, large pockets of radiation oncologists were centered in metropolitan areas with large academic centers. This finding corroborates previous findings from the ASTRO workforce committee that groups of ten or more radiation oncologists are more likely to be in academic centers. [17] The clustering of radiation oncologists in academic centers is perhaps due to recent increases in academic radiation oncology due to an influx of physician scientists in radiation oncology residency programs, or due to the attractiveness of technological resources available at academic centers.[46]

Our analysis found that access to radiation oncology services was allocated along socioeconomic and racial characteristics and provides information for policy makers on potential factors that affect radiation oncologist distribution, and could be used for future legislation aimed at physician recruitment to underserved areas. Although Hayanga et al found access to radiation oncologists to be associated with decreased minority population on the county level, our analysis found a positive association between minority

population and ROR within HSAs.[47] The reason for this difference is partly because our negative binomial regression model more accurately predicted radiation oncologist density given the distribution compared to the linear regression used in their analysis. Also, our geographic units of analysis were HSAs, which better predict patterns of healthcare usage compared to counties. Additionally, unlike previous analysis, our ROR outcome variable accounts for the variation in population density across the United States and is more accurate than gross physician totals. Moreover, unlike previous analyses, our analysis excluded counties located in US territories such as Guam, Puerto Rico and the US Virgin Islands that generally have disproportionate minority populations and skewed access to specialists. Our findings suggest that, although racial disparities in cancer outcomes have been well documented, minority populations generally reside within HSAs in close proximity to radiation oncologists. [48]

Our findings highlight the problem of physician recruitment to rural areas. Recently, rural physician recruitment efforts have faced obstacles because of the technological gap that exists in rural settings. This problem is evermore important in a highly technical field like radiation oncology and has translated to patient dissatisfaction as physician retention rates in rural areas have decreased. [46] Traditional policymakers have theorized that market forces and rural incentives would decrease geographic disparities as the workforce increases. [49] However, we found little or no decrease in geographic variability of radiation oncologists to accompany a growth in the workforce. The significant non-physician personnel needed to operate radiation therapy facilities could also be a factor in the geographic maldistribution of radiation oncologists. The workforce shortages of radiation oncologists exacerbated with corresponding workforce

shortages in non-physician personnel, such as dosimetrists and medical physicists [50], perhaps make it difficult provide cost-effective quality radiation therapy in rural areas in the United States. Recently, studies have suggested the solution to geographic maldistribution is not increased recruitment to rural areas, but rather, technical innovations that increase the efficiency of healthcare for rural populations. [51-54] An example of a treatment innovation, specifically in radiation therapy, is hypofractionated treatment, as performed for breast radiotherapy in Canada (the so-called, "Canadian fractionation") where geographic distance between radiation oncology centers is even more severe than the United States.

We explored the implications of a geographically maldistributed workforce on management of prostate cancer. Patients in HSAs without radiation oncologists were more likely to choose active surveillance even when possessing high-risk disease. Additionally, patients in HSAs lacking the presence of radiation oncologists were more likely to undergo radical prostatectomy as primary treatment. Our findings corroborate previous evidence that found an association with patient visits to urologists and radiation oncologists and patient prostate cancer treatment choice.[31,55] Our study highlights the need for multidisciplinary care in order for patients to make informed decisions regarding prostate cancer treatment. Additionally, recent evidence that suggests multidisciplinary care alters treatment patterns for patients with localized prostate cancer.[55] Interestingly, we found primary care physician density to be associated with increased active surveillance of prostate cancer. This is perhaps because patients who have access to primary care physicians are more likely to successfully monitor low-risk prostate cancer through active surveillance. Lastly, we confirmed previous evidence suggesting marital

status, age, and patient race are related to patient decisions to pursue active surveillance of prostate cancer in lieu of curative therapy.

The geographic distribution of the radiation oncology workforce is associated with differences in prostate cancer mortality. The presence of a single radiation oncologist in a county was associated with a statistically significant reduction in prostate cancer specific mortality. The improvement in prostate cancer mortality persisted even when adjusting for regional prostate cancer incidence, other physician densities, and socioeconomic factors. Interestingly, incremental increases of radiation oncologists in a county did not yield incremental benefits in outcomes, suggesting a 'plateau effect' when a region becomes saturated with radiation oncologists. These results corroborate with similar studies that found diminishing returns with increases in physician supply.[15,56]

Radiation therapy is one of the most common treatments for prostate cancer. Although our study does not directly test the clinical implications of radiation therapy and prostate treatment, it does highlight a potential association between the availability of radiation therapy and improved prostate cancer outcomes. Radiation oncologist density may be a surrogate for specialized oncology care, specifically the presence of large cancer centers with multidisciplinary tumor boards and a variety of non-radiation prostate cancer specialists. Although improved outcomes cannot definitively be attributed to the presence of a radiation oncologist, our findings of improved prostate cancer mortality, despite adjustment for urologist and allergist/immunologist density, speak to the robustness of the specific association between radiation oncologist density and prostate cancer mortality. Another possible explanation for our findings is that radiation oncologists are a proxy for other general oncology indicators that could not be fully

adjusted for in our multivariate model. For example, the presence of a large cancer center with access to more advanced treatment technologies and multidisciplinary tumor boards to better coordinate prostate cancer care between urologists and radiation oncologists. Our study also highlighted previously cited racial disparities in prostate cancer outcomes. Counties with larger proportions of Caucasians were associated with increased prostate cancer mortality reduction. This is likely because minorities have been shown to present with more advanced prostate cancer which carries a worse prognosis.[57] Furthermore, when adjusting for other factors known to influence cancer outcomes, such as socioeconomic factors (median household income, population education level) the presence of radiation oncologists was associated with prostate cancer mortality, highlighting the relative uniqueness of radiation oncologist to prostate cancer management.

Our, analysis found increasing urologist density to have a more profound effect on prostate cancer specific mortality compared to radiation oncologist density. The reasons for this are likely multifactorial. Firstly, because of greater number of urologists compared to radiation oncologists the impact of urologists on prostate cancer mortality maybe more easily seen. Secondly, because urologists are involved in the screening and diagnosis of prostate cancer in addition to surgical treatment, increased density of urologists may be associated with increased likelihood to be diagnosed at an earlier stage with a more favorable prognosis. Conversely, radiation oncologists serve only a curative role in prostate cancer treatment and require another clinical provider, typically a urologists or primary care physician, to refer a prostate cancer patient to them. In a counties with poor primary care and urologist presence radiation oncologists may be

faced the challenge of treating higher stage prostate cancers that were not screened and thusly diagnosed later.

County-level analysis confirmed the previously described geographic maldistribution of radiation oncologists across health services areas. Large segments of the population live in counties without a radiation oncologist, and this in turn is associated with increased prostate cancer mortality. To complicate the problem, creating an equitable distribution of radiation oncology services remains difficult. Unlike many other medical specialties, radiation oncologists require significant equipment to provide treatment, making radiation therapy relatively insular to increasingly popular telemedicine initiatives. Additionally, the large investment required to start a radiation oncology practice may contribute to apprehension of radiation oncologists entering the field to establish a practice in an underserved area.

The mechanism by which radiation oncologist density is related to prostate cancer mortality is difficult to pinpoint. Prior work has shown that radiation oncologist and urologist density was not predictive of whether patients receive any curative therapy. Rather, individual patient characteristics, such as marital status, are predictive of receipt curative treatment.[58] However, our previous analysis suggests radiation oncologist and urologist density are predictive of whether patients choose radiation therapy or surgery as the treatment modality for prostate cancer.[59] It is plausible that regional physician density is related to aspects of management about which patients are less informed, such as nuanced treatment modalities, but decisions related to larger questions of whether to receive curative treatment are ultimately personal ones. Furthermore, as geographic differences in prostate cancer mortality have mainly been attributed to differences in

disease stage related to time of diagnosis, an aspect of care with which radiation oncologists are not typically involved, the density of radiation oncologists may be of less utility.[26] Perhaps it is the radiation oncologist's role in providing truly multidisciplinary cancer care that most influences mortality. Where previous investigators found an association between urologist density and prostate cancer mortality, we found a similar association for radiation oncologists, even when adjusting for the presence of urologists and variations in prostate cancer incidence.[15] Therefore, our two studies in combination highlight the importance of multidisciplinary care in the management of patients with prostate cancer.

We found that the improvement in prostate cancer mortality did plateau beyond a radiation oncologist density of 1.0 per 100,000. Reasons for this diminishing return may be because incremental improvement in prostate cancer mortality when comparing higher density categories was small relative to the large improvement in mortality from the addition of the first radiation oncologist to a county. This plateau effect has been seen in similar studies of the physician, dermatology, neonatology workforces.[5,8,56] Moreover, prostate cancer can be relatively indolent, in contrast to cervical cancer or head and neck cancers. Patients residing in areas with an oversubscribed radiation oncologist can potentially wait until prostate cancer treatment is available, perhaps mitigating the need for additional radiation oncologists to improve time between diagnosis and treatment.

Limitations

Our analysis has several limitations. First, the physician location data from the AMA masterfile does not capture physicians who have multiple practices in different

regions, and therefore it is possible that we have overestimated the geographic clustering of radiation oncologists. However, though we believe that radiation oncologists are more likely to have multiple physician practice locations compared to primary care providers, we suspect that if radiation oncologists have multiple practices that they would be within the same HSA. Unfortunately, this is unable to be confirmed by our data. Second, the masterfile has been shown to underestimate physician shortages in rural areas. [60] Third, our study does not capture other barriers to care such as lack of health insurance and whether radiation oncology centers accept Medicaid payment for their services. Finally, our analysis cannot provide an optimal ROR because we did not relate geographic distribution to clinical outcomes. Future analysis should focus on finding the radiation oncologist distribution that will optimize cancer outcomes. We were unable to assess the impact of the availability of various radiation treatment modalities (EBRT, brachytherapy, SBRT), as no information was recorded as to the type of treatment available at each practice location. Another limitation of our study is the exclusion of rural counties when studying the association between radiation oncologist density and mortality within the United States. Unfortunately, the prostate cancer mortality data for some rural regions was unavailable. Nevertheless even if that data were available, the paucity and relatively maldistribution of radiation oncologists and urologists among rural counties would make it difficult to establish any reliable relationship between physician density and prostate cancer outcomes. What remains clear however is the variation in prostate cancer outcomes in resource poor and resource rich regions. Further studies focused on rural counties will be needed to better generalize the results of our analysis to rural areas. Additionally, patient-specific characteristics were unattainable using the merged State

Cancer Profiles data. Additionally, our analysis is subject to a theoretical lead-time bias associated with patients in underserved areas potentially being diagnosed later and with more advanced disease. This is due to a lack of available county-level stage and grade data. This limitation is present in studies of this nature[6,8] and was somewhat mitigated by adjusting for geographic variations in prostate cancer incidence. Finally, given the relative slow growth of prostate cancer, current mortality is likely related to treatment options available upwards of 10-year prior. A multivariate model replacing current physician densities with physician densities from 1995 yielded similar results. This is likely because the geographic maldistribution of the radiation oncology and urology workforces have remained relatively unchanged within the last 15 years.[15,16] The relationship between historical health system resources and long-term outcomes of a population in the years following is an interesting topic for future studies. Nevertheless, previously published studies of our similar nature[6] our study is fundamentally an analysis of the current variations in healthcare systems across the United States. Using current physician densities as a proxy for current general oncology infrastructure and allows the study the relative robustness of current healthcare systems. Our analysis ultimately comments less on the well-established curative relationship between urologists and radiation oncologists for prostate cancer, rather more on the relationship between resource rich/poor regional healthcare systems and overall prostate cancer outcomes. In spite of these limitations, our analysis provides a first step in understanding the relationship between variations in the radiation oncologist workforce and prostate cancer mortality and serves as an impetus for further study of the effect of regional radiation oncologist therapy resources in the management of prostate cancer.

Conclusion

In this comprehensive geographic analysis of the physician workforce we highlighted a maldistribution of the radiation oncology workforce that has persisted for over a decade. The geographic variations are associated with tangible differences in the treatment of prostate cancer patients and regional prostate cancer mortality rates. Further policy discussions addressing the physician workforce must focus not only on gross numbers, but also geographic distribution. Although it is difficult to quantify the ideal number of radiation oncologists needed in various regions in the United States, our study raises questions regarding whether certain regions are lacking adequate numbers of radiation oncologists. Geographic aware policies are needed to optimize the physician workforce and provide quality oncology care throughout the United States.

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