

Cancer Therapy: Clinical**Spatial Analyses Identify the Geographic Source of Patients at a National Cancer Institute Comprehensive Cancer Center**Shu-Chih Su¹, Norma Kanarek², Michael G. Fox³, Alla Guseynova³, Shirley Crow⁴, and Steven Piantadosi⁵**Abstract**

Purpose: We examined the geographic distribution of patients to better understand the service area of the Sidney Kimmel Comprehensive Cancer Center at Johns Hopkins, a designated National Cancer Institute (NCI) comprehensive cancer center located in an urban center. Like most NCI cancer centers, the Sidney Kimmel Comprehensive Cancer Center serves a population beyond city limits. Urban cancer centers are expected to serve their immediate neighborhoods and to address disparities in access to specialty care. Our purpose was to learn the extent and nature of the cancer center service area.

Experimental Design: Statistical clustering of patient residence in the continental United States was assessed for all patients and by gender, cancer site, and race using SaTScan.

Results: Primary clusters detected for all cases and demographically and tumor-defined subpopulations were centered at Baltimore City and consisted of adjacent counties in Delaware, Pennsylvania, Virginia, West Virginia, New Jersey and New York, and the District of Columbia. Primary clusters varied in size by race, gender, and cancer site. Spatial analysis can provide insights into the populations served by urban cancer centers, assess centers' performance relative to their communities, and aid in developing a cancer center business plan that recognizes strengths, regional utility, and referral patterns.

Conclusions: Today, 62 NCI cancer centers serve a quarter of the U.S. population in their immediate communities. From the Baltimore experience, we might project that the population served by these centers is actually more extensive and varies by patient characteristics, cancer site, and probably cancer center services offered. *Clin Cancer Res*; 16(3); 1065–72. ©2010 AACR.

Spatial analysis (1, 2) has been widely used in public health by such fields as epidemiology (3) to serve as a tool in the geographic surveillance of diseases. At the same time, hospital cancer registry data contain crude but substantial information about the characteristics of patients. Detection of spatial patterns (4) provides insights into the service population and the reach of a cancer center (4, 5). Several statistical approaches (6–8) have been adopted to identify clusters (9–11), which confirm and quantify the existence of stable service areas that may be defined by density of events proximal to the service provider.

Although all National Cancer Institute–designated comprehensive cancer centers serve a rather large area because of their offering of specialized services (12), a consistent definition of the population from which a center draws patients has been neither described nor implemented.

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Consequently, default service areas are conceived of as either very small, as in the immediate city or zip code, or a large but well-defined area, such as the surrounding state(s).

Catchment area studies to date have focused on market penetration and proximity (12–19). Approaches of setting a minimum distance traveled or time traveled and capturing an established percentage of all patients served are subjective determinations. SaTScan's assessment of homogenous groupings that differ statistically from the other areas engages the same criteria without presetting levels. This objectivity may be considered an advantage when, in addition to patient characteristics, market forces regulate patient volume (14).

In this report, we will explore the source of the patient population seeking cancer care at the Sidney Kimmel Comprehensive Cancer Center (SKCCC) in Baltimore, MD as a geographic clustering phenomenon. Not only will information about the densest areas of patient recruitment be obtained, demographics will highlight geographic area differences for subpopulations.

Materials and Methods

Sources of data. The Johns Hopkins Hospital (JHH) maintains an American College of Surgeons–certified cancer registry and is affiliated with the SKCCC, a National Cancer Institute–designated comprehensive cancer center.

Translational Relevance

This study delineates a 58-county, seven-state cancer services (catchment) area for a National Cancer Institute comprehensive cancer center centered in Baltimore City, its home jurisdiction. Cluster software (SaTScan) is a statistical tool for determining a contiguous geographic area that differs from the surrounding area in volume relative to resident population at risk of cancer and thus determines cancer services (catchment) area boundaries. The approach may be employed to identify cancer center program market strengths, to adjust the center's business plan, and to assess the level of specific services, such as clinical trial recruitment, within the catchment area. As illustrated in this report, the exercise of determining catchment area may be replicated for cancer site, gender, race and other patient characteristics.

Cancer cases from the JHH Cancer Registry diagnosed or treated during the period 1998 to 2002 were used for analysis. The JHH cancer registry contained information such as place of residence, gender, age, race, cancer site, year of diagnosis, and patient status (analytic/nonanalytic). County-specific cancer deaths (1998) were obtained from the National Center for Health Statistics.

Outcome variable. Cancer patients included in this analysis included those who were diagnosed or received all or part of their first course of treatment at SKCCC and were considered analytic cases. Cases originally diagnosed and initially treated at an outside facility that came to SKCCC for treatment of recurrent, metastatic, or persistent disease were defined as nonanalytic cases. In addition, patients who came to SKCCC for only a second opinion were excluded. Over the 5-y period, there were 27,009 analytic and nonanalytic cases among SKCCC patients. For this geographic analysis, we considered 25,853 patients reporting a continental U.S. residence.

Outcome variable. The residential address at the time of diagnosis or treatment for each case was reviewed and assigned a county, borough, or parish Federal Information Processing Standards code number according to the zip code recorded in the patient file (20). Individual patient level data were grouped into county aggregates and county-specific patient volume.

Independent variables. Patient characteristics were examined using county aggregates by gender, race, and cancer site. Thus, aggregate case count was the number of cases seen in each county by demographic characteristic. We examined major Surveillance Epidemiology and End Results sites that provided at least 5% of the cases overall; sites enumerated were breast, colon, lung, pancreas, and prostate.

Data analysis. Spatial Scan Statistic (SaTScan) version 6.01 (National Cancer Institute, Bethesda MD)⁶ was used

⁶ <http://www.satscan.org/>

to identify spatial clusters of counties with a homogeneous and high ratio of SKCCC cancer cases to all county cancer deaths. SaTScan (21, 22) has been widely used in epidemiology studies for geographic surveillance and disease control purposes (1). It provides a visual tool by which to identify clusters and potential clusters of disease (23, 24). Using a Poisson model, county-specific case count was treated as the outcome, whereas all county cancer deaths served as the population surrogate of the population with cancer in each county. The Poisson model assesses the cluster whereas considering the underlying density of cancer cases in a county. Spatial patterns were assessed with Kulldorff's spatial scan statistic. Instead of using the default value of 50% of the total cases as the maximum cluster size in SaTScan, we set a more modest value, 10% of the cases at risk, to be the maximum cluster size so that we might detect secondary and relatively small clusters outside the Baltimore area when they exist. Counties were identified and mapped according to Federal Information Processing Standards codes.

Nonparametric Spearman correlation tests were implemented in R for testing trend across years. χ^2 tests of independence were calculated in Stata 9.0. For the purposes of this study, $P < 0.05$ was considered statistically significant.

Results

SKCCC patient population (cancer cases). Between 1998 and 2002, 95.7% of cancer patients registered in the JHH cancer registry lived in the continental United States. Of those patients (Table 1), more than half (58.2%) resided in Maryland. The ratio of males to females was ~3:2. Nearly 83% were Caucasian and 15% were African American. Age was distributed in the following manner over 5 years: 2.4% were ages <18 years, 65.6% were ages 18 to 64 years, and 32.0% were ages 65 years and older.

Analytic cases comprised the majority of cases (81.1%) over the 5-year time period.

Prostate cancer predominated among the cancer sites diagnosed or treated at SKCCC with that site comprising 24.2% of the case load. Breast cancer was second, accounting for 9.2% of all cases, and lung cancer was the distant third highest contributor of cases at 6.6%. Together, these three sites comprise 40% of the SKCCC patient volume of those residing in the continental United States.

Statistical tests for increasing or decreasing trend suggested no significant time trends for any population subgroup. With much consistency over time and no trends detected for any population subgroup (data not shown), this analysis focused on spatial analysis without regard to temporal effects.

Spatial distribution. Clusters of high patient-to-deaths ratios were identified using a spatial scan statistic. SaTScan was used to ascertain the location and size of the primary cluster and the existence of secondary clusters.

When SaTScan was applied to all SKCCC cancer patients seen during the period 1998 to 2002 living in the continental United States, a primary cluster of 58 contiguous

Table 1. Characteristics of SKCCC patients with continental U.S. residence (1998-2002), total and by residential status in identified primary spatial cluster

	Total patients No. (%) [*]	Total counties in primary cluster No.	Primary spatial cluster No. (%)	Outside the primary cluster No. (%)
All patients	25,853 (100)	58	19,655 (100)	6,198 (100)
Region				
Baltimore City	3,560 (13.8)	1	3,560 (18.1)	0 (0)
Maryland (excluding Baltimore City)	11,491 (44.4)	21	11,251 (57.2)	240 (3.9)
Adjacent states [†]	6,863 (26.5)	35	4,838 (24.6)	2,025 (32.7)
Remainder of the United States	3,939 (15.2)	1	6 (0.0)	3,933 (63.4)
Gender				
Female	10,185 (39.4)	58	8,622 (43.9)	1,563 (25.2)
Male	15,665 (60.6)	58	11,030 (56.1)	4,635 (74.8)
Race [‡]				
African American	3,739 (14.5)	15	3,486 (17.7)	253 (4.1)
Caucasian	21,337 (82.5)	58	15,526 (79.0)	5,811 (93.7)
Other	777 (3.1)	–	643 (3.3)	134 (2.2)
Age (y)				
<18	609 (2.4)	52	522 (2.7)	87 (1.4)
18-64	16,978 (65.6)	58	12,570 (64.0)	4,408 (71.1)
65+	8,266 (32.0)	58	6,563 (33.4)	1,703 (27.5)
Analytic [‡]				
Analytic	20,958 (81.1)	58	15,822 (80.5)	5,136 (82.9)
Nonanalytic	4,895 (18.9)	58	3,833 (19.5)	1,062 (17.1)
Selected cancer sites [§]				
Prostate	6,245 (24.2)	58	3,250 (16.5)	2,995 (48.3)
Breast	2,368 (9.2)	50	2,116 (10.8)	252 (4.1)
Lung	1,699 (6.6)	58	1,547 (7.9)	152 (2.5)
Pancreas	1,464 (5.7)	132	956 (4.9)	508 (8.2)
Colon	895 (3.5)	58	770 (3.9)	125 (2.0)
All others	13,182 (51.0)	–	11,016 (56.0)	2,166 (34.9)

*Percentages were rounded to total 100%.

[†]Adjacent states include Delaware, District of Columbia, Pennsylvania, Virginia, and West Virginia.

[‡] χ^2 test across years with $P < 0.05$.

[§]These are the five largest contributors to patient volume and percentages do not add to 100%.

counties around Baltimore City (Fig. 1) was identified. These 58 counties contributed 19,655 cancer cases seen at the SKCCC and a corresponding 20,686 deaths. This cluster included all Maryland counties except Allegany and Garrett ($n = 22$), the westernmost counties of the state, Virginia counties ($n = 21$), Pennsylvania counties ($n = 8$), Delaware counties ($n = 3$), West Virginia ($n = 2$), New Jersey ($n = 1$) counties, and the District of Columbia. The primary cluster accounted for 19,655 patients, 76% of the SKCCC cases residing in the continental United States. Among patients in this primary cluster, more were African Americans (18%). In addition, patients in the primary cluster were slightly younger, less often male, and only slightly less often an analytic case compared with all continental U.S. patients

(Table 1). Among patients belonging to the primary cluster of all cancer cases, 16.5% were diagnosed with prostate cancer, 10.8% were with breast cancer, and 7.9% with lung cancer—a total of 35.2% for these three sites.

Among all cancers, four smaller secondary clusters were identified. However, only the cluster composed of counties in New York and Pennsylvania ($n = 9$) was statistically significant and represented a small fraction of all possible cases (0.72%). Table 1 presents all significant primary clusters.

Primary clusters. The primary cluster overall identified in SaTScan and for males and females (Fig. 1); colon, lung, and prostate cancers (Fig. 2; data not shown for all categories); adult patients (Fig. 3); and Caucasians (Fig. 4)

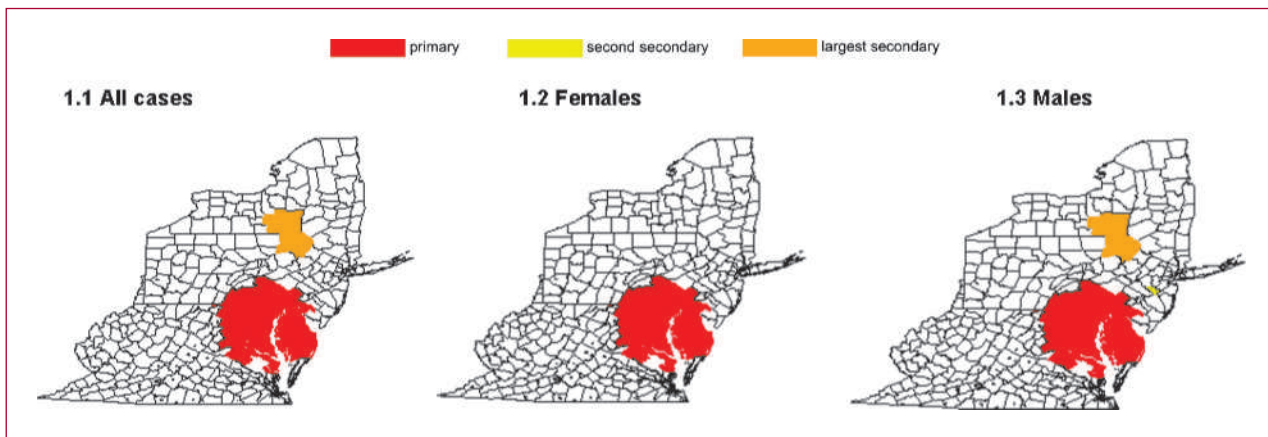


Fig. 1. Statistically significant clusters detected among SKCCC patients with continental U.S. residence, all cases, males, and females (1998-2002).

included the same 58 counties identified in the all cancers primary cluster (Fig. 1). All primary clusters are “centered” at Baltimore City and were composed of counties in Maryland, Delaware, New Jersey, Pennsylvania, Virginia, West Virginia, and District of Columbia. We display one cancer site-specific primary cluster comprised of about double the number of counties—a primary pancreas cluster was

made up of 132 contiguous counties (Fig. 2). In contrast, the primary cluster of breast cancer cases is smaller, at 50 counties, as is the primary cluster for cases aged <18 years ($n = 52$; Fig. 3). Notably, the statistically significant primary cluster for African Americans consists of the fewest counties, 15 in all, yet it also has 85.8% of all African Americans diagnosed or treated at the SKCCC (Fig. 4).

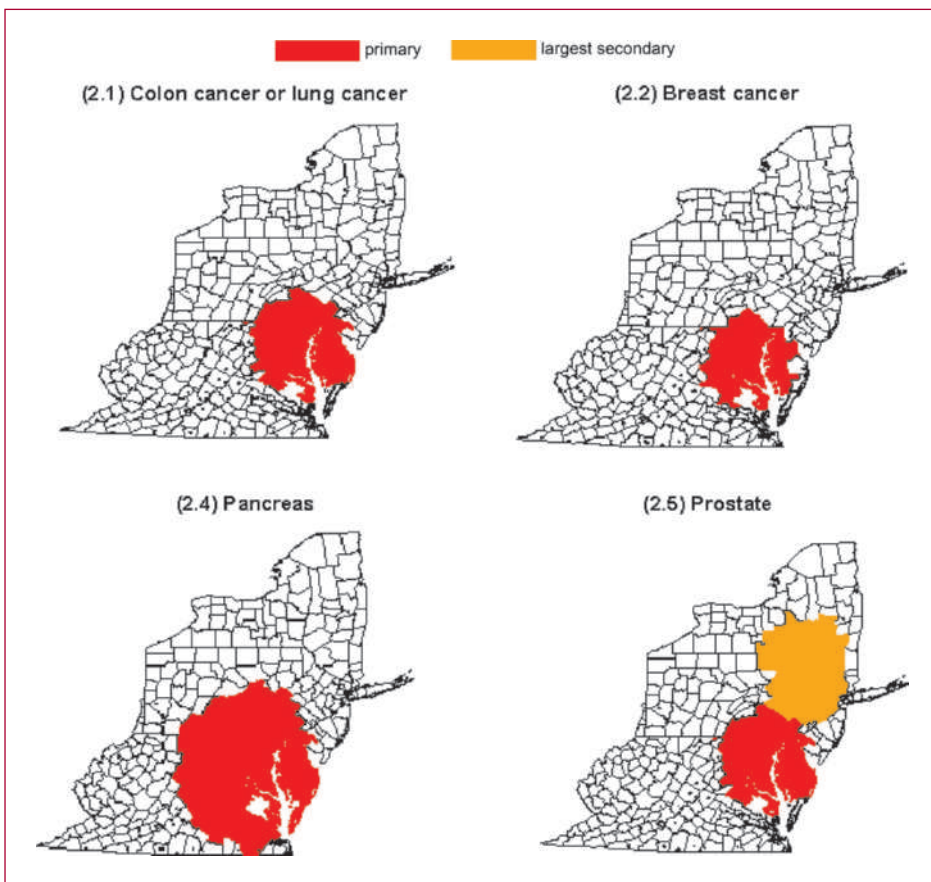
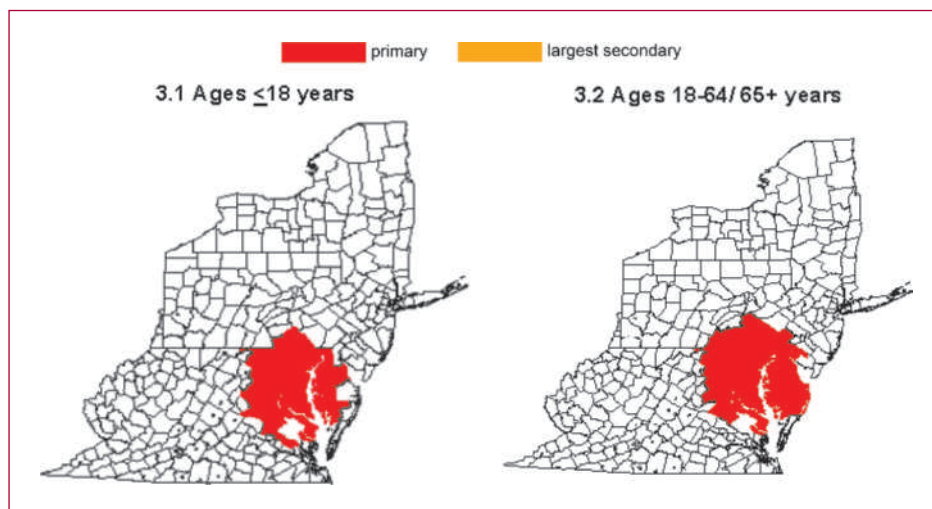


Fig. 2. Statistically significant clusters detected among SKCCC patients with continental U.S. residence by selected cancer site (1998-2002).

Fig. 3. Statistically significant clusters detected among SKCCC patients with continental U.S. residence by age group (1998-2002).



The primary cluster identified was similar across the sites of colon, lung, and prostate cancers which included 58 counties in Maryland and nearby states, the primary cluster detected for all cases. Note that there is a statistically significant secondary cluster of prostate cancers. The cancer site-specific maps (Fig. 2) visually illustrate the differences in cluster size, whether it is a geographically small area or a broader area, serving different subpopulations.

A majority of each subgroup's population was captured in the primary cluster. More than 90% of patients with lung cancer resided in the identified primary cluster. In contrast, only 52% of the patients with prostate cancer resided in the identified primary cluster, indicating that a sizable portion of the patients with prostate cancer did not reside in the Baltimore region and might be referred to the SKCCC from more distant medical providers.

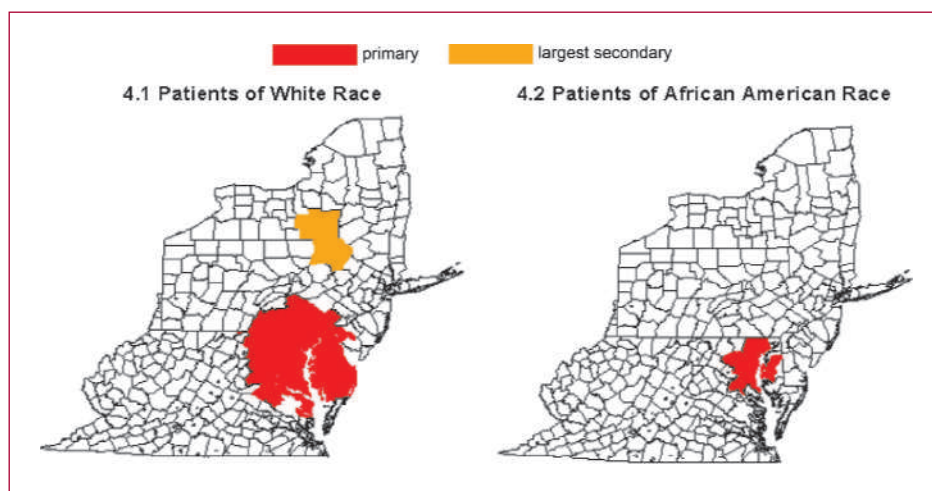
Secondary clusters. Looking beyond primary clusters, there are significant secondary clusters detected among many subpopulations. The secondary cluster sizes were

relatively smaller when compared with the primary cluster size and appeared in the states other than Maryland. At least one statistically significant secondary cluster was identified for all cases (Fig. 1), males (Fig. 1), Caucasians (Fig. 4), and patients with prostate cancer (Fig. 2). As illustrated in the figures, statistically significant secondary clusters located in New York and Pennsylvania consisted of nine counties.

Although the initial primary cluster for males and females was identical (58 counties), two statistically significant secondary clusters for males were identified (Fig. 1) and include the New Jersey/New York/Pennsylvania group ($n = 9$), and a statistically important secondary cluster consisting of a New Jersey county. Secondary clusters not reaching statistical significance tended to be rather distant from Baltimore and are not shown.

Among patients with prostate cancer, the primary cluster identified was identical to the one for all cases (58 counties), but in addition, there was a statistically significant and

Fig. 4. Statistically significant clusters detected among SKCCC patients with continental U.S. residence by race (1998-2002).



relatively large (9.5%) secondary cluster identified that was comprised of 43 counties in New Jersey, New York, and Pennsylvania.

Conclusions

This study illustrates the application of spatial statistical methodology to assess the source of SKCCC cancer patients. SaTScan is helpful in exploring the spatial clusters of SKCCC cancer patients seeking care from across the United States and provides insights into service patterns. Using the Poisson model and SaTScan to JHH cancer registry data provided feedback on the size of primary clusters centered on Baltimore City. Results confirmed that the majority of the cancer cases came from areas adjacent to Baltimore City, although the areas themselves varied in reach based on the demographics of the population or the characteristics of the cancer (Figs. 1–4). Meanwhile, secondary clusters were also found for some patient subgroups, suggesting differing service patterns for certain cancer sites and demographics. These clusters no doubt reflect patient preferences, population density and location, referral patterns, and services offered. For instance, the pancreas cancer program at SKCCC maintains a pancreas cancer family history project, which may account for the

larger geographic area (i.e., primary cluster) from which pancreas cancer cases are drawn. Prostate cancer is over-represented in the patient population of the SKCCC, due in part, to a large surgical treatment program, which seems to create a regional pattern and concentrated, more distant referrals. On the other hand, common sites such as breast and lung cancer, where standard treatment may be considered well disseminated, the area from which patients derive tends to be somewhat smaller or average.

Secondary cluster analysis may serve the important function of identifying existing referral patterns or confirming the known but anecdotal relationships among providers. For instance, some secondary clusters of prostate cancer cases were identified. Cases in counties centered on Mercer County, NJ ($P = 0.01$) and South Carolina counties ($P = 0.116$) suggest referral patterns outside the normal proximity of primary clusters and merit further investigation. In the secondary cluster around Beaufort, SC, 37% of SKCCC patients from the area received treatment or diagnosis for prostate cancer and although not statistically significant may represent an important urological referral network.

One limitation of our analysis is that the underlying population with cancer was difficult to obtain or estimate. Although there are population-based registries emerging,

Table 2. Use of catchment area information to assess cancer portfolio and provide insight into service characteristics that shape the service profile

Population	Portfolio assessment*	Potential explanations for the size of the catchment area
Pancreas	(3) Barrier exists and may revolve around insurance or services.	Services are locally unavailable (25, 26), technology sensitive (25), or have high operative mortality (27, 28).
All cancers, prostate, [†] males, females, Caucasians	(1) Desirable service pattern exists but is vulnerable to changes in the market.	Cases are likely distant with better survival (29), referral sensitive (15), technology sensitive (25), ambulatory care sensitive (15, 30), severity-related admissions (15, 31, 32), and treatment may be less intense (33).
Lung, colorectal	(7) Indifferent or uninformed population segment exists or competition is operating.	Convenient services (26), contract selectivity (34), and hospitalization less likely with further distance (17) may determine this group.
Breast, children	(6) Relatively small market with moderate preferences.	Care may be ambulatory care sensitive (15, 30), for detection and treatment, as uptake of chemo is greater when in-area and a "cancer hospital" (35). Women less likely to travel (31). There may be treatment (33) and stage considerations (31, 32). There is generally less tolerance for long travel times for children and the oldest old (25, 31).
African Americans	(5) Relatively high preference for services in this population segment.	Palliative care is sought closer to home (36), distance traveled is dependent upon income or SES, insurance coverage may be a confounding factor (14), and population travels shorter distances or travel may take longer (31).

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NOTE: Greater percentage of total incidence than that observed for Maryland (low, 0-4%; medium, 5-14%; high, 15%+).

*Portfolio type according to MacStravic (25).

[†]Prostate cancer cases showed one primary cluster of 58 and one secondary cluster of 58.

they are not yet all at the same level of accuracy and availability for research, so incidence data could not be used. Instead, we used the county all-cancer deaths for 1 year as the population surrogate and a measure of its vulnerability to cancer in the construction of the Poisson model. This approach assumes that the surrogate is appropriate and constant across the whole 1998 to 2002 period. Use of 1 year's cancer deaths could contribute to the finding that there were few annual differences in SKCCC cancer cases across years. Despite this limitation, the identified clusters confirmed that SKCCC draws patients from a large, mid-Atlantic region and thus does not just serve as only a local treatment center. Patients not resident within the Baltimore area will come for treatment or diagnosis due to the physician group and specialized expertise at SKCCC. It's possible that in future years, states adjacent to Maryland will have complete and timely cancer incidence information by county and these numbers could and should be used to refine the population from which SKCCC patients derive.

We suggest that a description of one cancer center's patient volume would be useful in developing a credible rationale for statistics used to assess how a cancer center is performing relative to its community, and in developing a business plan that recognizes the center's strengths, utility in the region, and perhaps differential referral patterns. To illustrate how this might work for the SKCCC and other cancer centers, we show Table 2, which organizes potential explanations for the particular size configurations of various cancer sites and subpopulations according to the MacStravic portfolio assessment levels (25). At the SKCCC, genetic pancreas cancer investigations are facilitated by a family history registry and genetic counseling is offered. These specialized services are probably unique regional offerings. Prostate cancer is overrepresented in the SKCCC caseload, due in part to an abundance of patients with early stage disease who seek surgery only. In addition, prostate cancer is ambulatory care-sensitive due to prostate-specific antigen screening. Lung and colorectal cancer are treated in many other local hospitals; to gain more of this market, SKCCC would most likely need to address contract selectivity, which operates in most hospital markets. Female breast cancer patients benefit from comprehensive treatment, including chemotherapy, and literature suggests that both

women and those obtaining chemotherapy prefer closer distances. The small catchment area identified for African Americans may indicate preferences for local care as well, and shorter travel times. Thus, portfolio assessment can begin with data such as these and be applied to any cancer center. The SKCCC began this project however to better know and serve its patients that may be enrolled in clinical trials. Clinical trial recruitment, the provision of definitive treatment, and ultimately, survival, are all outcomes that are potentially related to the geography of cancer care.

In summary, mapping of cancer cases provides an illustrative tool for visualizing and considering cancer center service patterns. SaTScan analysis adds another layer for understanding the distribution of county cancer cases. First, it was able to identify and define a primary cluster centered on the location of the cancer center for all cancer cases and many patient population subgroups. Second, these primary clusters differ in the proportion of the total population served and number of counties included, which may be explained by the presence of specialized services at the cancer center or the abundance of similar services elsewhere. Third, secondary clusters identified may have administrative import in verifying informal referral patterns or quantifying the results of formal agreements. Fourth, we think analyses like these should be incorporated into National Cancer Institute reporting regarding patients served and service to the surrounding community. Last, this analysis may enable us to increase our understanding of patient behavior, especially as we reach out to minority, female, and young or elderly populations.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

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