A Population-Based Assessment of Proton Beam Therapy Utilization in California

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ABSTRACT

OBJECTIVES: Proton beam therapy (PBT) is a type of radiation therapy (RT) used for certain cancer types because it minimizes collateral tissue damage. The high cost and limited availability of PBT have constrained its utilization. This study examined patterns and determinants of PBT use in California.

STUDY DESIGN: Persons with diagnoses of all cancer types from 2003 to 2016 inclusive who had any type of RT were identified in the California Cancer Registry in this retrospective analysis.

METHODS: Cross-tabulations were performed to summarize the demographic characteristics of the study population, both for individuals who received PBT and for those who received other RT modalities. PBT use patterns over time were assessed. Multivariate logistic regression models assessed the effects of demographics and health insurance type on receipt of PBT.

RESULTS: Of the 2,499,510 people with a cancer diagnosis during the study period, 578,632 (23%) received some type of RT, and of these, 8609 received PBT (1.5%). PBT was most often used to treat cancers of the prostate (41.3%), breast (14.0%), eye (11.7%), lung (6.1%), and brain (6.0%). PBT use was highest in 2003-2004 and then declined over time. PBT use was significantly associated with being white or male, younger age, higher socioeconomic status, Medicare or dual Medicare-Medicaid insurance, uninsured/self-pay status, and proximity to treatment.

CONCLUSIONS: Significant differences exist in PBT use by demographics and health insurance type. The identified racial and socioeconomic disparities merit further investigation. More granular studies on both use patterns and effectiveness of PBT for specific cancers are needed to draw stronger conclusions about its cost-benefit ratio.

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Radiation therapy (RT) is an integral part of cancer care, with some estimates indicating that approximately 40% to 50% of patients undergo RT during their treatment course.[1-3] Technological advancements have resulted in the development of multiple modalities that deliver precise radiation doses to the tumor, resulting in less damage to surrounding healthy tissues. The most commonly used modalities are photon based and have evolved from conventional 2-dimensional to 3-dimensional (3-D) conformal radiation and intensity-modulated RTs.[4] Proton beam therapy (PBT) techniques have evolved in parallel. The heavier mass of protons, compared with photons, allows highly targeted, maximal doses of radiation to be delivered to the tumor but not beyond it, which is theorized to result in fewer proximal and late effects for select cancer types, including subsequent malignancies.[2] PBT is indicated for sarcomas and cancers of the brain and central nervous system (CNS) in children and adolescents, as concerns regarding late effects are particularly relevant for the cancer treatments in this population subgroup.[5-8] PBT is also indicated for certain rare cancers in adults (eg, tumors of the skull base, eye, and spine) because of tumor location and concern about radiation damage to adjacent structures.[9] Although there is little consensus regarding the comparative effectiveness of PBT for common adult cancer types,[9] advocates continue to press health plans to cover PBT for treatment of prostate, breast, and lung cancers, among others. In California, efforts in this regard have also been directed to the Department of Managed Health Care, which provides regulatory oversight of the majority of health plans in the state.

The high cost and increased use of radiation treatments have spurred calls from national cancer policy groups for research to determine utilization patterns and relative value of specific radiation modalities to both patients and society.[9,10] PBT has been available since the late 1980s, but its accessibility remains limited. This is due largely to high operational costs, leading many insurers to decline payment for PBT absent definitive evidence of its therapeutic superiority over other RT modalities. Additionally, high start-up costs of building PBT centers have limited the number of such sites, often causing patients to travel long distances for treatment.

TAKEAWAY POINTS

- Patients with cancer with Medicare insurance coverage were more likely to receive proton beam therapy compared with patients with private insurance.
- Compared with non-Hispanic whites, all other racial/ethnic groups had significantly lower odds of being treated with proton beam therapy, across various cancer types, after accounting for other relevant demographic and clinical factors.
- Policy makers should consider data on both utilization patterns and comparative effectiveness to develop policies to ensure that proton therapy is used appropriately and that its use is limited to populations for whom there is evidence of benefit.

Despite a recent increase in the number of proton centers under development in the United States, current and historical PBT utilization patterns are not well understood. The few national studies on this topic are confined to investigating PBT use among patients with prostate cancer using information with limited generalizability.[11-13] Because the availability and development of PBT centers vary significantly by region, state-specific utilization patterns merit investigation.

We examined determinants of PBT use over time across all cancer types in California, a state with a large and diverse population. This study was undertaken in part to inform leadership of the Department of Managed Health Care about the statewide patterns and determinants of PBT use. California had 2 operating proton centers (Loma Linda University in Loma Linda and California Protons in San Diego) and 1 proton ocular center (University of California, San Francisco) during the study period.

METHODS

Study Population

Individuals with a diagnosis of any type of cancer during the period 2003-2016 who had any type of RT during their first course of treatment were identified in the California Cancer Registry (CCR). The CCR is the largest population-based cancer registry for a geographically contiguous area in the world, collecting incidence reports on more than 160,000 newly diagnosed cancer cases annually. Although the CCR contains information on cases diagnosed from 1988 forward, cases diagnosed prior to 2003 were excluded because collection of information on the specific radiation modality started in 2003, prior to which PBT use was minimal.

Description of Variables

Patients with cancer were classified into 2 groups on the basis of radiation treatment modality: (1) individuals who received PBT and (2) those who received all other RT modalities, including photons, electrons, intensity-modulated RT, and conformal or 3-D therapy. Details of radiation treatment administered during the first course of treatment are captured in the registry through medical record review. *International Classification of Diseases for Oncology, Third Edition* codes were used to identify cancer sites.[14]

Information on primary and secondary payer at diagnosis was combined to create 6 categories of health insurance: private insurance (including Medicare with private supplement), Medicare only, Medicaid, dual Medicare-Medicaid coverage, county (including local publicly administered health plans), and uninsured/self-pay. Persons having Medicare-Medicaid dual eligibility are of particular interest from a cancer care perspective because disproportionate numbers of these persons have poorer access to care and worse outcomes compared with the general population consequent to advanced age and adverse socioeconomic circumstances.[15,16] The uninsured/self-pay category included persons without insurance and those with any balance due after insurance payments because of deductibles or noncovered services.

Stage of disease was classified according to the Surveillance, Epidemiology, and End Results summary staging schema.[17] Race/ethnicity was coded as non-Hispanic white (white), black, Hispanic, and Asian, according to the North American Association of Central Cancer Registries' Hispanic and Asian/Pacific Islander Identification Algorithms.[18,19] Age at diagnosis was grouped into 4 categories: younger than 40, 40 to 64, 65 to 74, and 75 or older. Socioeconomic status (SES) was measured using an established aggregate score based on patients' block group of residence at the time of diagnosis.[20] Comorbidity was measured using a previously validated index created by linking CCR data with statewide hospital discharge, ambulatory care, and emergency encounters data files.[21] As the latter 2 data sources are available in California only from 2005 forward, comorbidity statistics were calculated only for patients with cancer diagnosed from 2005 to 2016. Distance to treatment was calculated using residential information at the time of diagnosis and grouped into 3 categories: less than 50 miles, 50 to 100 miles, and more than 100 miles.

Statistical Analysis

Descriptive statistics were generated to characterize the study population by radiation modality (PBT vs all other radiation modalities). Chi-square tests were used to assess differences in frequency distributions of categorical variables. PBT utilization patterns over time by type of cancer and health insurance were evaluated. Multivariate logistic regression modeling was used to identify independent determinants of PBT, with all other types of radiation as the referent category. Independent variables in the model included cancer type, sex, age category, race/ethnicity, SES, health insurance type, distance to treatment, and stage of tumor. Six models were generated; 1 included all cancers combined (with cancer type as a covariate), and 5 other models included each of the top 5 cancers in which PBT treatment was used. As comorbidity data were available only for patients treated in select settings, a considerable percentage (19.6%) were missing this information. Multivariate models were run both with and without comorbidity scores as covariates. Because both sets of models yielded similar results (data not shown), only models without comorbidity are presented.

TABLE 1. Characteristics of Patients With Cancer Receiving Radiation Treatment by Modality, California, 2003-2016 (n = 578,632)[a,b]

Variable	Proton Beam Therapy n (column %)	Other Radiation Therapy n (column %)	Total n (column %)
Sex			
Female	2950 (34.3)	322,376 (56.6)	325,326 (56.2)
Male	5658 (65.7)	247,575 (43.4)	253,233 (43.8)
Other/unknown	1 (0.0)	72 (0.0)	73 (0.0)
Age category in years			
<40	680 (7.9)	37,825 (6.6)	38,505 (6.7)
40-64	3684 (42.8)	269,061 (47.2)	272,745 (47.1)
65-74	2864 (33.3)	154,318 (27.1)	157,182 (27.2)
≥75	1381 (16.0)	108,819 (19.1)	110,200 (19.0)
Race/ethnicity			
Non-Hispanic white	6088 (70.7)	360,238 (63.2)	366,326 (63.3)
Non-Hispanic black	482 (5.6)	37,237 (6.5)	37,719 (6.5)
Hispanic	1269 (14.7)	100,345 (17.6)	101,614 (17.6)
Asian/PI	699 (8.1)	65,240 (11.5)	65,939 (11.4)
Other/unknown	71 (0.9)	6963 (1.2)	7034 (1.2)
SES			
Low	1813 (21.1)	140,214 (24.6)	142,027 (24.5)
Medium	2987 (34.7)	199,834 (35.1)	202,821 (35.1)
High	3809 (44.2)	229,975 (40.3)	233,784 (40.4)
Health insurance type			
Private	5142 (59.7)	364,401 (63.9)	369,543 (63.9)
Medicare	1116 (13.0)	26,236 (4.6)	27,352 (4.7)
Medicaid	509 (5.9)	51,902 (9.1)	52,411 (9.1)
Dual Medicare-Medicaid	1387 (16.1)	81,441 (14.3)	82,828 (14.3)
County	74 (0.9)	6016 (1.1)	6090 (1.1)
Uninsured/self-pay	142 (1.6)	7048 (1.2)	7190 (1.2)
Unknown	239 (2.8)	32,979 (5.8)	33,218 (5.7)
Summary stage			
In situ/localized	6171 (71.7)	283,397 (49.7)	289,568 (50.1)
Regional	1375 (16.0)	164,854 (28.9)	166,229 (28.7)
Remote	797 (9.2)	100,274 (17.6)	101,071 (17.4)
Unknown	266 (3.1)	21,498 (3.8)	21,764 (3.8)
Comorbidity			
0	3211 (48.2)	266,600 (54.1)	269,811 (54.1)
1	664 (10.0)	76,103 (15.5)	76,767 (15.4)
2	237 (3.5)	27,199 (5.5)	27,436 (5.5)
≥3	251 (3.8)	26,693 (5.4)	26,944 (5.4)
Unknown	2292 (34.4)	95,805 (19.5)	98,097 (19.6)
Distance to treatment in miles			
<50	3872 (45.0)	98,321 (17.2)	102,193 (17.7)
50-100	1546 (18.0)	168,706 (29.6)	170,252 (29.4)
>100	3191 (37.1)	302,996 (53.2)	306,187 (52.9)

(continued)

RESULTS

A total of 578,632 of 2,499,510 (23%) patients in the CCR were treated with some form of radiation in their first course of treatment during the study period; this excludes 285 individuals for whom radiation modality was not specified. A total of 8609 individuals received PBT (1.5% of patients receiving RT), whereas the remaining 570,023 patients with cancer received other forms of RT. PBT was most often used to treat prostate (41.3%), breast (14.0%), eye (11.8%), lung (6.1%), and brain (6.0%) cancers (**Table 1**). Consistent with prostate cancer being the most common cancer type treated with PBT, a significantly larger proportion of patients with cancer receiving PBT were male (66%).

The racial/ethnic distribution of the PBT group was disproportionately white (70.7%) compared with the other RT group (63.2%). A 3-fold larger proportion of individuals treated with PBT were insured by Medicare at the time of diagnosis compared with the proportion on Medicare in the other RT group. A large majority of PBT patients received a diagnosis at an in situ/localized stage (71.7%) compared with half of patients treated with other RT. A significantly smaller proportion of patients treated with PBT had 1 or more comorbid conditions compared with the non-PBT group (17.3% vs 26.4%, respectively). A significantly larger proportion of the PBT group lived less than 50 miles from a PBT center compared with the non-PBT group (45.0% vs 17.2%, respectively).

Rates of PBT use for all cancers and breast, lung, and brain cancers were highest in 2003-2004 and then declined over time (**Figure 1**). Rates of PBT use among patients with eye and orbit cancers were the highest, with half of patients receiving PBT from 2003 to 2008, and decreased steadily after this period to 35% in 2016. PBT use among patients with prostate cancer steadily increased from 2004 to 2011, declining thereafter.

There was significant variation in PBT use over time by insurance type (**Figure 2**). PBT use was highest in 2003 and then declined among patients with private and Medicaid insurance. PBT use among patients insured by Medicare increased by 262% from 2003 to 2011, after which time it sharply declined. The PBT use pattern among individuals with dual Medicare-Medicaid insurance approximated the trend for Medicare patients, albeit less dramatically.

The results of the multivariate model with all cancers included identified several significant determinants of PBT use (**Table 2**). Patients with eye/orbit cancers had greater odds of receiving PBT compared with those with other cancer types (odds ratio, 90.9; 95% CI, 81.8-100.9). Patients with prostate and brain/CNS cancers had 4-fold and 2-fold significantly greater odds of PBT, respectively, than patients with other cancer types, whereas patients with breast cancer were 15% less likely to receive PBT. Women had 13% lower odds of receiving PBT compared with men. Patients were less likely to receive PBT as age increased. Patients 75 years or older had 68% decreased odds of receiving PBT compared with those younger than 40. Black, Hispanic, and Asian patients had significantly lower odds (11%-16%) of receiving PBT compared with white patients. Patients

TABLE 1. *(Continued)* Characteristics of Patients With Cancer Receiving Radiation Treatment by Modality, California, 2003-2016 (n = 578,632)[a,b]

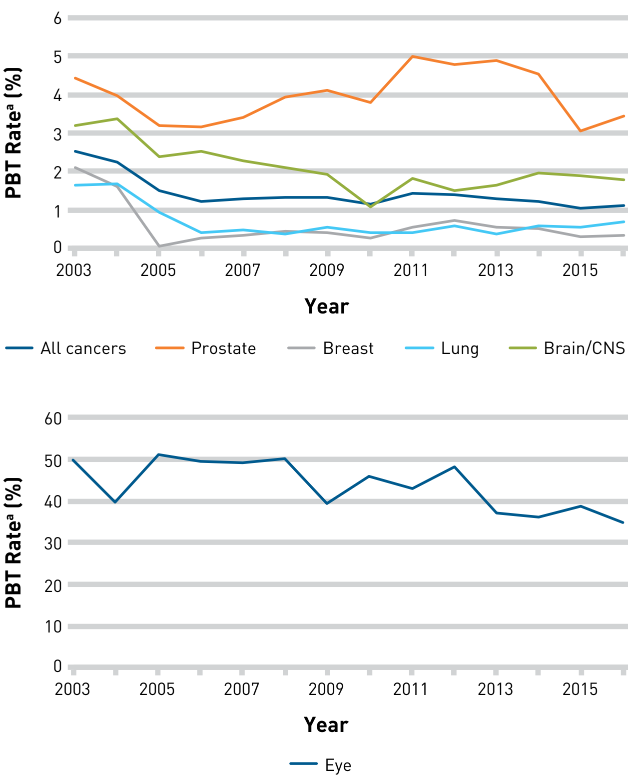
Variable	Proton Beam Therapy n (column %)	Other Radiation Therapy n (column %)	Total n (column %)
Cancer type			
Prostate	3555 (41.3)	83,705 (14.7)	87,260 (15.1)
Female breast	1209 (14.0)	173,624 (30.5)	174,833 (30.2)
Eye/orbit	1012 (11.8)	1334 (0.2)	2346 (0.4)
Lung	525 (6.1)	73,341 (12.9)	73,866 (12.8)
Brain/CNS	513 (6.0)	22,937 (4.0)	23,450 (4.0)
Lymphoma/leukemia	254 (2.9)	25,958 (4.6)	26,212 (4.5)
Liver/intrahepatic bile duct	208 (2.4)	11,628 (2.0)	11,836 (2.1)
Oral cavity/pharynx	197 (2.3)	23,086 (4.1)	23,283 (4.0)
Female genital	179 (2.1)	27,472 (4.8)	27,651 (4.8)
Colon and rectum	174 (2.0)	31,606 (5.5)	31,780 (5.5)
Other sites	783 (9.1)	95,332 (16.7)	96,115 (16.6)
Years of diagnosis			
2003-2004	1954 (22.7)	77,263 (13.6)	79,577 (13.7)
2005-2007	1718 (20.9)	122,594 (21.5)	124,312 (21.5)
2008-2010	1655 (19.2)	124,217 (21.8)	125,872 (21.8)
2011-2013	1779 (20.7)	121,560 (21.3)	123,339 (21.3)
2014-2016	1503 (17.5)	124,029 (21.8)	125,532 (21.7)

CNS indicates central nervous system; PI, Pacific Islander; SES, socioeconomic status.

[a]*P* <.001 for all variables.

[b]The comorbidity data in the tables exclude cases diagnosed 2003-2004, as ambulatory surgery and emergency encounters data in California (from which some of the comorbidity information is derived) are available only from 2005 forward.

FIGURE 1. Use of PBT by Year and Cancer Type in California, 2003-2016 (n = 578,632)[a,b]

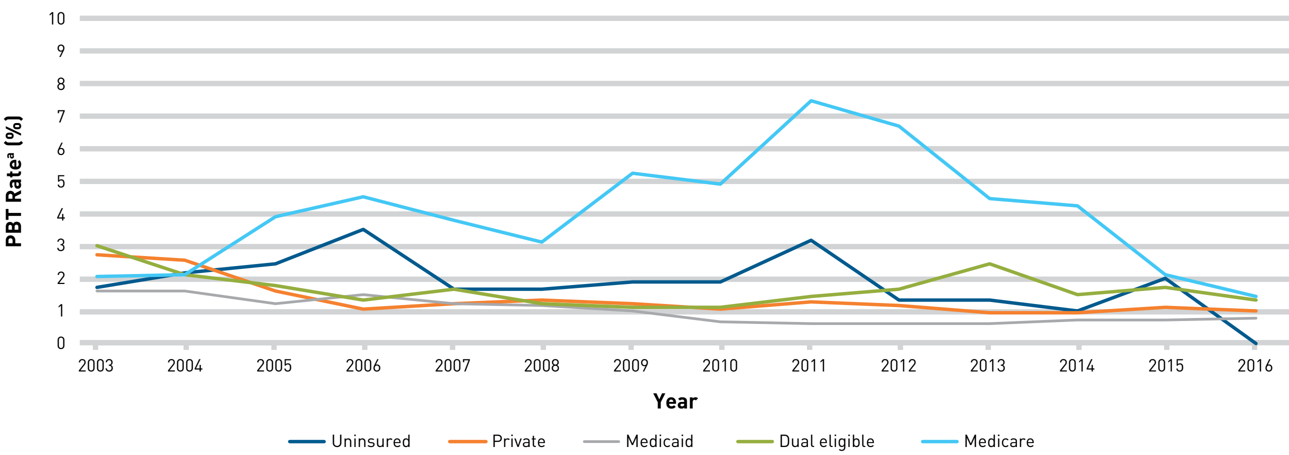


CNS indicates central nervous system; PBT, proton beam therapy.

[a]PBT rate refers to the percentage of patients who received radiation therapy who had PBT as the radiation treatment modality.

[b]*P* value for trend is <.001 for all cancer types.

FIGURE 2. Trends in PBT Use for All Cancers by Insurance Type, California, 2003-2016 (n = 578,632)[a,b]



PBT indicates proton beam therapy.

[a]PBT rate refers to the percentage of patients who received radiation therapy who had PBT as the radiation treatment modality.

[b]*P* value for trend is <.001 for all insurance types.

TABLE 2. Determinants of Proton Beam Therapy Use Among All Patients With Cancer Who Received Radiation Treatment (n = 578,632)

Variable	Odds Ratio (95% CI)
Sex	
Male	1.00 (–)
Female	0.87 (0.81-0.93)
Age category in years	
<40	1.00 (–)
40-64	0.59 (0.54-0.64)
65-74	0.43 (0.39-0.48)
≥75	0.32 (0.28-0.35)
Race/ethnicity	
Non-Hispanic white	1.00 (–)
Non-Hispanic black	0.85 (0.77-0.94)
Hispanic	0.84 (0.79-0.90)
Asian/PI	0.89 (0.82-0.97)
SES	
Low	1.00 (–)
Medium	1.14 (1.07-1.21)
High	1.23 (1.16-1.31)
Health insurance type	
Private	1.00 (–)
Medicare	3.84 (3.56-4.14)
Medicaid	1.04 (0.94-1.14)
Dual Medicare-Medicaid	1.66 (1.56-1.78)
County	1.25 (0.98-1.60)
Uninsured/self-pay	1.42 (1.19-1.69)
Stage	
In situ/localized	1.00 (–)
Regional	0.69 (0.65-0.73)
Remote	0.70 (0.64-0.77)
Distance to treatment in miles	
<50	1.00 (–)
50-100	0.25 (0.24-0.27)
>100	0.22 (0.21-0.24)
Cancer type	
Other	1.00 (–)
Prostate	4.50 (4.18-4.84)
Female breast	0.85 (0.78-0.92)
Eye/orbit	90.9 (81.8-100.9)
Brain/CNS	2.11 (1.90-2.34)
Lung	1.03 (0.93-1.14)
Time period of diagnosis	
2003-2004	1.00 (–)
2005-2007	0.51 (0.47-0.54)
2008-2010	0.49 (0.46-0.53)
2011-2013	0.56 (0.52-0.60)
2014-2016	0.47 (0.43-0.50)

CNS indicates central nervous system; PI, Pacific Islander; SES, socioeconomic status.

who lived more than 50 miles from a PBT center had 75% decreased odds of receiving PBT. A separate subanalysis of patients who lived within 50 miles of a PBT yielded largely similar results as the model with all patients with cancer included, with 2 notable exceptions. Black patients and patients on Medicaid who lived less than 50 miles from a PBT center had 21% and 29% higher odds, respectively, of receiving PBT compared with non-Hispanic whites and privately insured individuals (data not shown).

Increasing SES was associated with greater odds of PBT use; individuals in the highest SES stratum were 23% more likely to be treated with PBT relative to those in the lowest SES stratum. Patients on Medicare at the time of diagnosis had 4 times greater odds of receiving PBT compared with privately insured patients. Individuals with dual Medicare-Medicaid insurance and who were uninsured/self-pay were 66% and 42%, respectively, more likely to receive PBT than privately insured patients. Individuals with cancers diagnosed at regional and remote stages had 30% lower odds of receiving PBT than those diagnosed at a localized stage. Having any comorbidity was inversely associated with PBT receipt; those with a comorbidity index of 1 or more had 3% to 13% lower odds of PBT relative to individuals with no comorbidity. Patients with unknown comorbidity status had 26% higher odds of having PBT compared with patients with no comorbidity (data not shown).

Multivariate models by cancer site identified significant site-specific patterns in PBT use (Table 3). Patients with prostate, brain, and breast cancers had significantly lower odds of receiving PBT with increasing age, whereas patients with eye/orbit cancers aged 40 to 64 years and 65 to 74 years had 70% and 36%, respectively, greater odds of having PBT compared with individuals younger than 40 years. Blacks, Hispanics, and Asians with prostate and eye/orbit cancers had roughly half the odds of receiving PBT compared with their white counterparts. Asians and Hispanics with breast cancer had 21% and 31%, respectively, greater odds of receiving PBT compared with whites. Odds of PBT receipt were 29% and 32% greater for patients with prostate cancer in the medium and high SES levels, respectively, compared with those with low SES. Among patients with brain cancer, however, those in the 2 highest SES categories were less likely to receive PBT than patients with low SES.

Patients with Medicare had 2 to 5 times greater odds of receiving PBT compared with those with private insurance across all 5 cancer types examined. Patients with eye/orbit cancers with Medicaid had 67% greater odds of having PBT, whereas Medicaid-insured patients with prostate and breast cancers were 37% and 49%, respectively, less likely to have had PBT. Patients with prostate, eye, and breast cancers with dual Medicare-Medicaid coverage had 63%, 59%, and 39% greater odds of PBT, respectively, compared with privately insured individuals. Uninsured/self-pay patients with prostate cancer were nearly 5 times more likely to have received PBT, whereas those with eye/orbit cancers had 66% lower odds of PBT receipt compared with privately insured patients.

DISCUSSION

This analysis of PBT utilization patterns in California found site-specific patterns and associations between receipt of PBT and multiple factors, including cancer site, race/ethnicity, age, socioeconomic status, and insurance type. Three previous studies examined PBT use for prostate cancer using the National Cancer Database and Medicare files.[11,12,22] To the best of our knowledge, this is the first population-based study of PBT use across all cancer types and age groups, with the largest sample size of PBT recipients to date, and it is responsive to calls from national cancer policy groups for further research on PBT utilization patterns.

This study is particularly relevant given the recent increase in proton center development and rapidly rising costs of cancer treatment. The cost of building a proton center when the technology was first developed ranged from $120 million to $200 million, resulting in few centers being sited and rendering PBT inaccessible to most patients. Today, the cost of building these centers has dropped to $20 million to $30 million, which seems to have spurred development of several new PBT centers.[9] As of April 2018, there were 27 PBT centers in the United States, with 20 more in development.[23] These trends reflect renewed interest in PBT and underscore the need to better understand both utilization patterns and comparative effectiveness of this costly treatment. There is a dearth of completed randomized trials directly comparing proton-based with photon-based RT. The National Cancer Institute and the Patient-Centered Outcomes Research Institute are currently funding several prospective randomized trials comparing the effectiveness of protons and photons in common cancers.[24] Results from these trials should provide valuable evidence regarding the comparative effectiveness of these modalities.

Patients with Medicare were significantly more likely to receive PBT across all cancer types. Prostate cancer was the most common cancer for which patients received PBT. PBT centers have long promoted this modality for treatment of prostate cancer, along with other high-incidence cancers, despite a dearth of clinical evidence indicating PBT's superiority

TABLE 3. Determinants of Proton Beam Therapy Use by Cancer Type Among Patients With Cancer Who Received Radiation Therapy, California, 2003-2016 (n = 578,632)

Cancer Site Variable	Prostate (n = 87,260)[a] OR (95% CI)	Eye (n = 2346) OR (95% CI)	Brain (n = 23,450) OR (95% CI)	Female Breast (n = 174,833) OR (95% CI)	Lung (n = 73,866)[a] OR (95% CI)
Sex					
Male	N/A	1.00 (–)	1.00 (–)	N/A	1.00 (–)
Female	N/A	1.09 (0.92-1.29)	0.91 (0.77-1.09)	N/A	1.00 (0.84-1.18)
Age category in years					
<40	1.00 (–)	1.00 (–)	1.00 (–)	1.00 (–)	1.00 (–)
40-64	1.00 (–)	1.70 (1.21-2.38)	0.40 (0.33-0.49)	0.94 (0.71-1.25)	1.00 (–)
65-74	0.69 (0.64-0.75)	1.36 (0.94-1.97)	0.30 (0.22-0.40)	0.66 (0.49-0.90)	1.03 (0.83-1.18)
≥75	0.47 (0.42-0.52)	0.94 (0.64-1.38)	0.17 (0.11-0.26)	0.59 (0.42-0.83)	0.70 (0.83-1.28)
Race/ethnicity					
Non-Hispanic white	1.00 (–)	1.00 (–)	1.00 (–)	1.00 (–)	1.00 (–)
Non-Hispanic black	0.58 (0.51-0.67)	0.30 (0.09-1.08)	0.83 (0.53-1.30)	1.21 (0.95-1.54)	1.05 (0.74-1.47)
Hispanic	0.52 (0.46-0.59)	0.47 (0.34-0.65)	0.97 (0.77-1.21)	1.21 (1.02-1.42)	0.90 (0.65-1.26)
Asian/PI	0.55 (0.48-0.64)	0.55 (0.32-0.94)	0.71 (0.51-1.00)	1.31 (1.11-1.55)	1.39 (1.08-1.78)
SES					
Low	1.00 (–)	1.00 (–)	1.00 (–)	1.00 (–)	1.00 (–)
Medium	1.32 (1.20-1.46)	0.87 (0.67-1.13)	0.75 (0.60-0.94)	0.83 (0.70-0.98)	1.05 (0.83-1.34)
High	1.29 (1.17-1.43)	0.51 (0.40-0.66)	0.62 (0.49-0.79)	1.15 (0.98-1.35)	1.67 (1.33-2.11)
Health insurance type					
Private	1.00 (–)	1.00 (–)	1.00 (–)	1.00 (–)	1.00 (–)
Medicare	4.02 (3.63-4.45)	3.25 (2.26-4.67)	2.38 (1.49-3.80)	4.67 (3.84-5.66)	2.41 (1.84-3.17)
Medicaid	0.51 (0.37-0.69)	1.67 (1.08-2.58)	1.25 (0.97-1.59)	0.63 (0.48-0.82)	0.71 (0.48-1.06)
Dual Medicare-Medicaid	1.63 (1.49-1.79)	1.59 (1.20-2.12)	1.30 (0.93-1.84)	1.39 (1.13-1.71)	1.34 (1.08-1.67)
County	0.33 (0.14-0.80)	1.76 (0.68-4.58)	2.13 (1.31-3.44)	0.90 (0.43-1.90)	0.23 (0.03-1.63)
Uninsured/ self-pay	4.71 (3.74-5.92)	0.34 (0.15-0.79)	0.85 (0.45-1.61)	1.18 (0.61-2.28)	0.60 (0.22-1.61)
Summary stage					
In situ + localized	1.00 (–)	1.00 (–)	1.00 (–)	1.00 (–)	1.00 (–)
Regional	0.38 (0.32-0.45)	0.27 (0.17-0.41)	0.88 (0.67-1.15)	0.77 (0.67-0.88)	1.00 (0.76-1.33)
Remote	0.24 (0.18-0.34)	0.17 (0.08-0.36)	1.20 (0.72-2.01)	0.89 (0.62-1.26)	0.88 (0.68-1.13)

N/A indicates not applicable; OR, odds ratio; PI, Pacific Islander; SES, socioeconomic status.

[a]Models for prostate and lung cancers included 3 instead of 4 age categories because of minimal cell sizes: 64 years or younger, 65 to 74 years, and 75 years or older; for these 2 cancers, 64 years or younger is the referent group.

over other radiation treatment modalities.[22] It is possible that the sheer volume of the market for common cancers allows for greater return on the substantial investment to construct proton beam facilities.[25] Although coverage for PBT varies greatly by payer and cancer type, Medicare has had historically high rates of reimbursement for PBT for prostate cancer.[25]

The peak in PBT use observed in 2011 for prostate cancer and subsequent decline are consistent with Medicare reimbursement trends for PBT. Nationwide, from 2006 to 2009, the number of Medicare beneficiaries receiving PBT doubled due to a 68% increase in use for "conditions of possible benefit."[25] Prostate cancer falls into this category and is the main condition for which it is used. Individuals with dual Medicare-Medicaid insurance were significantly more likely to have received PBT, which is likely also a result of Medicare reimbursement trends for this treatment.

Although the absolute number of individuals who received PBT in California was highest for prostate cancer, the proportion of individuals receiving PBT was substantially greater among those with eye/orbit cancers, ranging from 35% to 50% over time. This finding is unsurprising given that 80% of the observed eye/orbit cancers were ocular melanomas, the main indication for PBT in eye cancers. This observation is also consistent with the association between older age and increased likelihood of PBT; ocular melanomas occur most commonly in older adults.[26]

Medicaid recipients with eye and orbit cancers had greater odds of receiving PBT compared with privately insured patients. Based on current evidence, PBT is the preferred treatment for ocular melanomas because it minimizes damage to nearby critical structures, resulting in high eye preservation rates.[27-29] The majority of eye and orbit cancers in this analysis were ocular melanomas (89%), a condition for which Medicaid allows reimbursement for PBT. Additionally, because 1 of California's 3 PBT facilities is a well-reputed ocular proton center, this finding may also reflect differential state-specific referral patterns.

Race/ethnicity was independently associated with PBT use for all cancers combined; all racial/ethnic groups were significantly less likely to have had PBT compared with white patients. Our study results indicating lower use of PBT among black and Hispanic patients are consistent with the results of previous population-based studies on PBT use in patients with prostate cancer.[11,12,22] The findings of lower PBT use among Asian patients with prostate and eye/orbit cancers are new and merit further investigation; they may reflect differences in physician referral patterns, patient self-advocacy for the treatment, clinical trial access, or proximity to the limited proton centers in the state. For orbital cancers, differences in the incidence of ocular melanoma compared with other common malignancies of the orbit, with increased incidence in Caucasians, may explain much of this difference.[30]

Higher SES was positively associated with PBT treatment for prostate cancer, consistent with previous findings.[11,12,22] Proximal distance to treatment was a strong determinant of PBT use. Findings reported by previous studies are mixed; one study found patients with localized prostate cancer were more likely to travel more than 100 miles or to relocate for PBT treatment,[11] whereas another reported similar findings to ours.[22] Among patients with eye/orbit and brain/CNS cancers, however, SES was inversely associated with PBT receipt. These findings may be at least partially explained by the relatively higher proportion of Medicaid-insured individuals among those who received PBT for these cancers compared with other cancer types.

Comorbidity was inversely associated with PBT receipt; patients who had any comorbidity had lower odds of receiving PBT, consistent with the results of previous studies in patients with prostate cancer.[11-13] Those with unknown comorbidity status had greater odds of receiving PBT than those with no comorbid conditions, suggesting that this group may be healthier because they were not found in the hospital discharge or ambulatory care files.

Limitations and Strengths

This analysis has limitations that should be considered when interpreting the results. CCR collects information on only the first course of treatment; if PBT was administered in a subsequent treatment round, this information would not be captured in this analysis. A previous study found radiotherapy to be underreported in the CCR, although there was high agreement between the CCR and medical records when radiotherapy was recorded.[31] Additionally, information on factors affecting care delivery, such as physician counseling and referral practices and patient choice, is not available in the CCR.

The quality and completeness of payer source information in the CCR varies by insurance type. One previous validation study of payer information in the CCR reported poor sensitivity (48%) but good specificity (98%) of the Medicaid information,[32] suggesting the possibility that Medicaid coverage is underestimated in the CCR. The effect of undercounting Medicaid coverage in the CCR cannot be predicted with certainty, although if Medicaid coverage were significantly underreported, then actual disparities among Medicaid beneficiaries might be greater than observed. Finally, given the small number of PBT centers in California, it is possible that this modality may not be a realistic option for many patients because of limited transportation resources, need for relocation, or other reasons.

Despite these limitations, this is the first population-based study to examine PBT use for all cancer types in a large and diverse population. The results confirm some previously identified determinants of PBT use for prostate cancer and contribute new information on use patterns for other cancers. Although previous studies using national databases included more granular information on RT, they focused on only 1 cancer site and had limited generalizability, as they were conducted using age-restricted populations and/or hospital- rather than population-based registries.

CONCLUSIONS

Differences exist in PBT use by demographic factors and health insurance. More granular studies in this regard, as well as on the proximal and late effects of PBT use for specific cancers, are needed to draw stronger conclusions about its cost-benefit ratio. Policy makers should consider information on utilization patterns and comparative effectiveness alike in developing policies that promote appropriate, evidence-based use of PBT and other advanced RTs. ■

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