Variation in Use of High-Cost Technologies for Palliative Radiation Therapy by Radiation Oncologists

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ABSTRACT

Background: Understanding the sources of variation in the use of high-cost technologies is important for developing effective strategies to control costs of care. Palliative radiation therapy (RT) is a discretionary treatment and its use may vary based on patient and clinician factors. **Methods:** Using data from the SEER-Medicare linked database, we identified patients diagnosed with metastatic lung, prostate, breast, and colorectal cancers in 2010 through 2015 who received RT, and the radiation oncologists who treated them. The costs of radiation services for each patient over a 90-day episode were calculated, and radiation oncologists were assigned to cost quintiles. The use of advanced technologies (eg, intensity-modulated radiation, stereotactic RT) and the number of RT treatments (eg, any site, bone only) were identified. Multivariable random-effects models were constructed to estimate the proportion of variation in the use of advanced technologies and extended fractionation (>10 fractions) that could be explained by patient fixed effects versus physician random effects. **Results:** We identified 37,361 patients with metastatic lung cancer, 3,684 with metastatic breast cancer, 5,323 with metastatic prostate cancer, and 8,726 with metastatic colorectal cancer, with 34%, 27%, 22%, and 9% receiving RT within the first year, respectively. The use of advanced technologies and extended fractionation was associated with higher costs of care. Compared with the patient case-mix, physician variation accounted for a larger proportion of the variation in the use of advanced technologies for palliative RT and the use of extended fractionation. **Conclusions:** Differences in radiation oncologists' practice and choices, rather than differences in patient case-mix, accounted for a greater proportion of the variation in the use of advanced technologies and high-cost radiation services.

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Background

Traditional fee-for-service payment models reward physicians for providing greater quantities of services and may have contributed to unsustainable increases in healthcare spending. This trend has spurred an increasing interest in alternative payment models, including recently proposed episode-based payment models for radiation oncology.[1] Many payment models seek to make physicians accountable for the overall costs of the services that they provide, with the goal of reducing unnecessary and high-cost care.[2] Critics, however, argue that much of the variation in the costs of care is a result of differences in the patient case-mix,[3] which is difficult for providers to control and challenging for payment models to adequately account for, rather than provider behavior, and that alternative payment models may lead to incentives to reduce essential or discretionary care. Although quality measures can be used to counter incentives to reduce care, highly discretionary treatments such as palliative care can have outcomes such as pain control that are more difficult to measure and can thus be at greater risk of underuse.

More than one-third of patients with metastatic cancer will receive palliative radiation therapy (RT) during the course of their disease. The costs of palliative RT under a fee-for-service model are primarily driven by 2 factors: number of treatments received and use of higher-cost advanced technologies. Given the limited life expectancy of many patients with metastatic cancers and often-delayed clinical responses to palliative RT, most studies have advocated for shorter courses of treatment.[4] In addition, aside from select patients with oligometastatic disease,[5–8] there is little evidence to suggest that the use of advanced technologies, such as intensity-modulated RT (IMRT) and stereotactic body RT, or a greater number of treatments is beneficial in the palliative setting for most patients.[4,9–11]

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To address the increasing costs of care, it is important to understand to what extent variation in the use of high-cost technologies and the number of treatments for palliative RT can be attributed to differences in patient and disease characteristics versus systematic differences in radiation oncologists' choices. This information can then be used to design payment models that promote the efficient use of resources in a manner that aligns care quality, value, and patient interests. If variation in care occurs predominantly because of clinical factors, then it could reflect appropriate decision-making by physicians treating patients with different characteristics. However, if this variation is largely explained by systematic differences in radiation oncologists' preferences for care, then payment models that seek to reduce variation in care may be justified. This study evaluated variation in the use of advanced radiation technologies and the number of radiation treatments received for patients with metastatic lung, breast, prostate, or colorectal cancer insured by Medicare fee-for-service plans by estimating the proportion of variation that could be accounted for by patient case-mix versus radiation oncologist choices.

Methods

Cohort

Full Cohort

We identified patients who were diagnosed with metastatic lung, breast, prostate, or colorectal cancer in 2010 through 2015 (AJCC 7th edition stage IV lung, breast, or colorectal cancer or stage IV prostate cancer with distant metastases) and who initiated RT within 1 year after diagnosis. To avoid radiation courses where treatment was planned but never delivered, we required all patients in the cohort to have at least 1 claim for radiation delivery.

Bone Metastases Cohort

In addition, from the cohort of patients receiving RT, we identified a secondary subgroup of patients who received RT for bone metastases. Radiation for bone metastases was defined if the patient had SEER-identified bone metastases (CS Mets at DX-Bone) at diagnosis and if the claims for their first course of radiation were associated with an ICD-9 diagnosis of bone metastases (ICD-9-CM diagnosis code 198.5).

Radiation Episode

RT typically consists of radiation planning followed by treatment delivery. We characterized an RT episode by first defining an index RT delivery date as the first date of service associated with an RT delivery code, using Medicare claims. We then identified claims for RT planning occurring no more than 28 days before and no more than 3 days after the index RT delivery date. The RT episode start date was defined as the index RT delivery date or the associated RT planning date, whichever came first. The cohort assembly diagram is shown in supplemental eFigure 1 (available with this article at JNCCN.org). We considered an RT episode as lasting 90 days from the episode start date, based on the length of RT episodes currently under consideration in the Centers for Medicare & Medicaid Services proposed alternative payment model.[12,13] The 9.6% of patients who had claims consistent with a second course of RT, which we defined as a second RT simulation claim within the 90-day episode, were excluded. Sensitivity analyses were performed using a 30-day RT episode length and included patients treated using multiple courses of RT during the episode.

Estimation of Medicare Spending

We used Medicare claims to estimate total Medicare spending on radiation services during the 90-day RT episode. Claims files included hospital outpatient and physician/carrier files, which accounted for both hospital-based and freestanding radiation facilities. All spending estimates were from the perspective of the Medicare program and were based on the Medicare payment variables in the outpatient and physician/carrier claims files to include both professional and technical charges from RT. We used the medical care component of the Consumer Price Index to adjust for inflation, and all costs were calculated based on 2018 US dollars.[14,15]

Outcomes

For each patient, the type of RT delivered (external-beam RT [EBRT; includes non-IMRT EBRT and IMRT]) and stereotactic RT was determined based on the technical complexity of treatment delivery from claims within the first radiation course (stereotactic RT > IMRT > non-IMRT EBRT). For patients treated using EBRT, the number of fractions was defined by summing the number of unique dates of service associated with an RT delivery code within the 90-day episode.

We considered the following RT outcomes for the full cohort: (1) number of fractions of EBRT, categorized into ≤10 versus >10 fractions (extended fractionation); (2) IMRT versus non-IMRT EBRT; and (3) stereotactic RT versus EBRT. For the bone metastases cohort, we considered the outcome of >10 versus ≤10 fractions of EBRT for bone metastases.

Physician Assignment

One radiation oncologist was assigned to each patient, using encrypted National Provider Identifiers (NPIs) associated with RT claims. Assignment was prioritized as follows so that each patient was assigned to a single radiation oncologist: first to the physician associated with the first clinical RT planning (93% of patients), followed by the physician associated with the patient's first treatment management claim (6% of patients), followed by the physician responsible for the patient's first RT claim of any type (1% of patients).

Statistical Analysis

For each outcome, the proportion of patients within each treatment/outcome group was summarized by means and percentages. We also summarized the distribution of Medicare payments by RT group and average RT costs per patient by physician. Considering that differences in Medicare spending on RT are driven primarily by variation in treatment practices, we constructed multivariable random-effects logistic regression models to examine the proportion of variation in treatment outcomes explained by components of the multilevel model: (1) patient-level fixed effects (age, sex, modified Charlson comorbidity index score,[16–18] marital status, year of diagnosis, disease type, and presence of metastases in bone, brain, liver, and/or lung); and (2) physician-level random effects (random intercept).

For a subset of 72% of patients, we were able to obtain data on their radiation oncologist's sex, year of graduation, and graduation from either a US or non-US medical school using the American Medical Association (AMA) Physician Masterfile. A subgroup analysis was conducted that controlled for these physician characteristics as additional variables.

Following a latent variable approach (ie, assuming that the observed dichotomous treatment outcome is based on an underlying latent continuous propensity for receiving a particular treatment), total variation was defined by: $\sigma_F^2 + \sigma_R^2 + \pi^2/3$, where σ_F^2 is the variance of the linear predictors from the fixed part of the model and σ_R^2 is the variance of the random effects.

The variation attributable to the fixed effects, represented by $\sigma_F^2/(\sigma_F^2 + \sigma_R^2 + \pi^2/3)$, was estimated by the sample variance of the fixed-effects linear predictor. The variation attributable to the physician random effects, represented by $\sigma_R^2/(\sigma_F^2 + \sigma_R^2 + \pi^2/3)$, was estimated by the random-effects variance.[19]

Because providers may choose treatments based on factors affecting prognosis that are not fully captured in the SEER-Medicare data, we performed additional analyses separating the cohort into patients who survived <6 versus ≥6 months.

Results

Using data from the SEER-Medicare linked database, we identified patients diagnosed with metastatic lung (n=37,361), prostate (n=5,323), breast (n=3,684), and colorectal (n=8,726) cancers in 2010 through 2015 who satisfied the inclusion criteria. Among these patients, 12,626 (34%) with lung cancer, 992 (27%) with breast cancer, 1,174 (22%) with prostate cancer, and 761 (9%) with colorectal cancer received a course of EBRT or stereotactic RT within 1 year of diagnosis. Construction of the full study cohort is summarized in supplemental eFigure 1. For the secondary subgroup, a total of 4,193 patients (2,931 with lung cancer, 465 with breast cancer, 707 with prostate cancer, and 90 with colorectal cancer) had bone metastases at diagnosis recorded in SEER and had a first course of RT that was associated with an ICD-9 diagnosis of bone metastases.

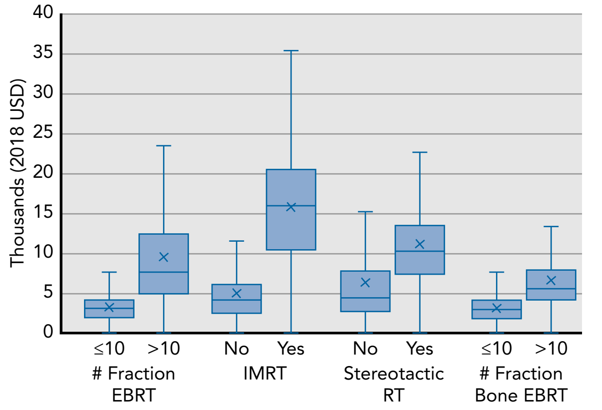

Figure 1. Medicare reimbursement for radiation therapy, by technology and number of fractions. Restricted to patients without multiple clinical treatment planning codes within the 90-day episode. Reimbursements for number of fractions, IMRT, and stereotactic RT did not control for site of treatment. Horizontal line: mean; X: median; thin bars: maximum/minimum; shaded box: interquartile range.
Abbreviations: EBRT, external-beam radiation therapy; IMRT, intensity-modulated radiation therapy; RT, radiation therapy.

Patient and disease characteristics by disease site are summarized in Table 1. Overall, 47%, 31%, 19%, and 23% of patients had SEER-identified bone, brain, liver, and lung metastases at diagnosis, respectively. Distribution of metastatic sites differed by diagnosis. For example, 43% of patients with lung cancer, 73% with breast cancer, 90% with prostate cancer, and 15% with colorectal cancer had bone metastases at diagnosis. We identified 1,741 unique radiation oncologists in our cohort, with a median number of patients per physician of 5 (range, 1–64).

Figure 1 summarizes unadjusted Medicare reimbursements for palliative RT by fractionation and use of radiation technologies. In our cohort, 12% of patients treated using EBRT received IMRT, and 9% treated using EBRT or stereotactic RT received stereotactic RT. Overall, 49% of patients treated at any

Table 1. Characteristics of Overall Cohort, by Cancer Type

	Lung n (%)	Breast n (%)	Prostate n (%)	Colorectal n (%)	Overall n (%)
Total patients, N	12,626	992	1,174	761	15,553
Age group, y					
66–69	3,253 (26)	255 (26)	241 (21)	188 (25)	3,937 (25)
70–74	3,799 (30)	250 (25)	302 (26)	193 (25)	4,544 (29)
75–79	2,851 (23)	203 (20)	244 (21)	152 (20)	3,450 (22)
≥80	2,723 (22)	284 (29)	387 (33)	228 (30)	3,622 (23)
Sex					
Male	6,612 (52)	15 (2)	1,174 (100)	390 (51)	8,191 (53)
Female	6,014 (48)	977 (98)	0 (0)	371 (49)	7,362 (47)
Race					
White	10,974 (87)	849 (86)	996 (85)	646 (85)	13,465 (87)
Black	1,029 (8)	109 (11)	118 (10)	75 (10)	1,331 (9)
Other	623 (5)	34 (3)	60 (5)	40 (5)	757 (5)
Rural residence					
No	10,220 (81)	833 (84)	958 (82)	623 (82)	12,634 (81)
Yes	2,406 (19)	159 (16)	216 (18)	138 (18)	2,919 (19)
College education quintile[a]					
1 (lowest)	2,663 (21)	161 (16)	218 (19)	167 (22)	3,209 (21)
2	2,598 (21)	183 (18)	223 (19)	151 (20)	3,155 (20)
3	2,490 (20)	211 (21)	232 (20)	156 (21)	3,089 (20)
4	2,503 (20)	234 (24)	233 (20)	138 (18)	3,108 (20)
5	2,372 (19)	203 (20)	268 (23)	149 (20)	2,992 (19)
State Medicaid buy-in					
No	10,687 (85)	840 (85)	1,041 (89)	629 (83)	13,197 (85)
Yes	1,939 (15)	152 (15)	133 (11)	132 (17)	2,356 (15)
Poverty rate					
Low (<10%)	5,588 (44)	499 (50)	573 (48)	333 (43)	6,993 (45)
High (≥10%)	7,038 (56)	493 (50)	601 (51)	428 (56)	8,560 (55)
Marriage status					
Married/Partner	6,822 (54)	377 (38)	747 (64)	368 (48)	8,314 (53)
Single	5,804 (46)	615 (62)	427 (36)	393 (52)	7,239 (47)
Modified CCI score[b]					
0	6,134 (49)	635 (64)	712 (61)	490 (64)	7,971 (51)
1	3,416 (27)	211 (21)	237 (20)	152 (20)	4,016 (26)
≥2	3,076 (24)	146 (15)	225 (19)	119 (16)	3,566 (23)
Treatment location					
Freestanding center	3,960 (31)	305 (31)	452 (39)	228 (30)	4,945 (32)
Hospital	8,666 (69)	687 (69)	722 (62)	533 (70)	10,608 (68)
Metastases at diagnosis[c]					
Bone	5,478 (43)	725 (73)	1,062 (90)	111 (15)	7,376 (47)
Brain	4,561 (36)	118 (12)	18 (2)	50 (7)	4,747 (31)
Liver	2,317 (18)	167 (17)	45 (4)	456 (60)	2,985 (19)
Lung	3,014 (24)	261 (26)	83 (7)	267 (35)	3,625 (23)

(continued on next page)

Table 1. Characteristics of Overall Cohort, by Cancer Type (cont.)

	Lung n (%)	Breast n (%)	Prostate n (%)	Colorectal n (%)	Overall n (%)
Year of diagnosis					
2010	2,291 (18)	168 (17)	162 (14)	156 (21)	2,777 (18)
2011	2,096 (17)	177 (18)	184 (16)	138 (18)	2,595 (17)
2012	2,143 (17)	161 (16)	184 (16)	123 (16)	2,611 (17)
2013	2,101 (17)	157 (16)	196 (17)	101 (13)	2,555 (16)
2014	2,017 (16)	177 (18)	214 (18)	127 (17)	2,535 (16)
2015	1,978 (16)	152 (15)	234 (20)	116 (15)	2,480 (16)
Region					
Northeast	2,422 (19)	242 (24)	247 (21)	159 (21)	3,070 (20)
South	3,851 (31)	266 (27)	270 (23)	201 (26)	4,588 (30)
Midwest	1,818 (14)	132 (13)	132 (11)	83 (11)	2,165 (14)
West	4,535 (36)	352 (35)	525 (45)	318 (42)	5,730 (37)

Abbreviation: CCI, Charlson comorbidity index.
[a]Percent of persons aged ≥25 years with at least 4 years of college education in the patient's census tract.
[b]Determined from claims from 1 month through 13 months before diagnosis. Deyo-Romano-Klabunde modification of the Charlson score.[16–18]
[c]Not mutually exclusive. Based on SEER variables that identify sites of distant metastatic involvement at the time of diagnosis. Patients with unknown status for a particular site (2% for bone metastasis, 3% for brain metastasis, 3% for liver metastasis, and 4% for lung metastasis) were designated as not having involvement at that site.

site and 33% of patients treated for bone metastases received >10 fractions during a 90-day episode. Using a greater number of fractions or more advanced technologies was associated with higher costs. For example, the mean reimbursement for 1 to 10 fractions of radiation was $3,246 compared with $9,578 for >10 fractions. Likewise, non-IMRT versus IMRT episodes cost a mean of $5,057 versus $15,813, and nonstereotactic EBRT versus stereotactic RT episodes cost a mean of $6,331 versus $11,122.

When physicians were divided into quintiles by mean radiation cost per patient, we found that physicians in the highest cost quintiles were more likely to use a greater number of radiation treatments and were more likely to use stereotactic RT and IMRT treatments. For example, the mean number of radiation fractions used for bone metastases was 6.7 versus 16.4 for physicians in the lowest versus the highest cost quintiles. Furthermore, physicians in the lowest versus the highest cost quintiles used IMRT for 3% versus 45% of their patients insured by Medicare. Figure 2 shows mean Medicare reimbursement, use of stereotactic RT, use of IMRT, and radiation fractionation for the full cohort along with radiation fractionation for the bone metastases cohort by physician cost quintile. Sensitivity analysis that considered an episode to be 30 days revealed similar results, although the mean number of fractions was reduced compared with a 90-day episode.

Because variation in practice may result from differences in the patient case-mix, we sought to determine the proportion of the variation in use that was a consequence of differences in patient case-mix versus differences in physician practice patterns. Tables 2 and 3 provide the results of the multilevel models, which shows the effect of patient-case mix variables compared with physician effects on the variation in the use of radiation technologies and fractionation in the study cohort. We found that for the use of all advanced technologies and of extended fractionation, practice pattern variations among radiation oncologists accounted for a larger proportion of the observed variation than did patient case-mix. Physician effects accounted for 31.8% of the variation in IMRT use, whereas patient case-mix accounted for 16.9%. Likewise, physician effects accounted for 43.2% of the variation in the use of stereotactic RT compared with 15.1% for patient case-mix.

Although physician effects explained a smaller percentage of the variation seen in the use of extended fractionation, they still accounted for a larger proportion of the variation than did patient case-mix, with 14.4% versus 7.0% attributed to physician variation versus patient case-mix for extended fractionation to any site and 20.0% versus 4.4% for extended fractionation to bone metastases. Finally, we found that for the use of advanced technologies and for extended fractionation, the random-effects variance was statistically significant in all models, meaning that choice of treatment was influenced by systematic differences in individual radiation oncologist practice patterns rather than by chance. Notably, a later year of diagnosis was associated with less use of extended fractionation but increased

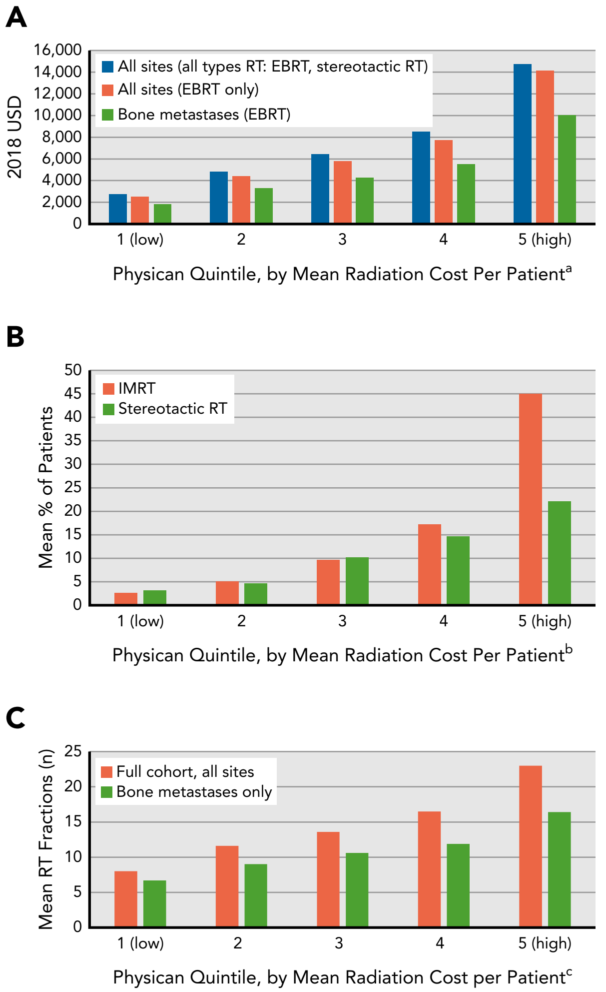

Figure 2. (A) Medicare reimbursement, (B) use of advanced technologies[a], and (C) number of radiation fractions[b] by physician cost quintile. For each physician, the mean number of fractions received by patients or the percentage of patients receiving a particular technology was calculated. Descriptive statistics were calculated from these physician-level estimates. Estimates not adjusted by patient case-mix.

Abbreviations: EBRT, external-beam radiation therapy; IMRT, intensity-modulated radiation therapy; RT, radiation therapy.

[a]Percentage of patients receiving IMRT was calculated from among all patients treated with EBRT (IMRT and non-IMRT EBRT); percentage receiving stereotactic RT was calculated from among all patients treated using all types of RT (EBRT or stereotactic RT).

[b]Number of radiation fractions was calculated from among all patients treated using EBRT. Patients receiving stereotactic RT were not included because the definition of stereotactic RT requires <5 fractions.

use of advanced technologies. Sensitivity analyses varying the length of the episode to 30 days and including patients who had evidence of multiple courses of radiation occurring within the episode did not substantially affect these results. Additional sensitivity analyses, excluding the 27% of physicians with only 1 patient in the cohort, also did not substantially affect the results.

Radiation oncologists' years since medical school graduation, medical school location, and sex were available for the 72% of patients whose claims included an NPI that was recorded in the AMA Physician Masterfile. Among this subgroup of patients, we found that female physicians (9.6% vs 11.6%; adjusted odds ratio [aOR], 0.75; 95% CI, 0.57–0.98; $P=.03$), physicians who graduated from medical school after 1990 (12.2% vs 10.5%; aOR, 1.30; 95% CI, 1.04–1.62; $P=.03$), and US medical school graduates (12.6% vs 11.0%; aOR, 1.54; 95% CI, 1.15–2.06; $P<.01$) were more likely to use IMRT than male physicians, physicians who graduated in 1990 or earlier, and non-US medical school graduates, respectively. Physicians who graduated after 1990 were also more likely to use stereotactic RT than those who graduated in 1990 or earlier (11.2% vs 6.8%; aOR, 1.52; 95% CI, 1.19–1.94; $P<.01$), and female physicians were less likely to use extended fractionation for any site compared with male physicians (49.3% vs 54.0%; aOR, 0.83; 95% CI, 0.72–0.96; $P=.02$). However, even when these individual physician characteristics were included in the multilevel model, physician random effects continued to explain a greater proportion of the variation in choice of fractionation and technology use compared with patient-level fixed effects.

After dividing the cohort into those who had survived for <6 versus ≥6 months, we found that in both cohorts physician variation continued to explain a larger proportion of the variation in fractionation and use of advanced technologies compared with patient case-mix. In the cohort surviving <6 months, physician random effects versus patient case-mix explained 39.4% versus 14.7% of IMRT, 45.2% versus 30% of stereotactic RT, 13.1% versus 3.7% of extended fractionation to any site, and 12.7% versus 5.1% of extended fractionation for bone metastases. For the cohort surviving ≥6 months, physician random effects versus patient case-mix explained 28.8% versus 18.5% of IMRT, 41.9% versus 19.1% of stereotactic RT, 20.0% versus 10.2% of extended fractionation to any site, and 29.6% versus 1.4% of extended fractionation for bone metastases.

Discussion

We found that variations in the use of IMRT, stereotactic RT, and extended fractionation among patients with metastatic solid tumors were more strongly associated with differences in radiation oncologists' behavior than with patient case-mix. As expected, there was far greater use of high-cost technologies and extended radiation courses among the highest-cost physicians.

We observed that although the use of extended fractionation decreased over time, the use of advanced

Table 2. Variation in Treatment Attributed to Patient Case-Mix Versus Physician Random Effects

	Extended Fractionation for EBRT	IMRT	Stereotactic RT	Extended Fractionation for Bone Metastases
Total				
Patients	14,095	14,095	15,553	3,695
Physicians	1,673	1,673	1,741	1,097
Proportion of variation explained by:				
Physician random effect	14.4%	31.8%	43.2%	20.0%
Patient case-mix (fixed effects)	7.0%	16.9%	15.1%	4.4%
Physician random-effects variance	0.55 ($P\leq.001$)	1.53 ($P<.001$)	2.50 ($P<.001$)	0.82 ($P<.001$)

The models include patient-level fixed effects and a random intercept for physicians.
Abbreviations: EBRT, external-beam radiation therapy; IMRT, intensity-modulated radiation therapy; RT, radiation therapy.

technologies increased. This reduction in the use of extended fractionation is consistent with multiple studies showing no significant difference in pain control among patients with uncomplicated bone metastases who receive single versus multifraction treatment[10,11,20] and subsequent national efforts to reduce the number of radiation fractions used in palliative treatment.[11,21,22]

Nevertheless, we found that the effect of physician variation on care was more pronounced for the adoption of high-cost radiation technologies, such as IMRT and stereotactic RT, than for the number of treatments delivered. This finding suggests that efforts to reduce the costs of palliative RT should not be limited to guidelines on fractionation. Radiation oncologists often decide on the number of treatments delivered based on prior training and experience, whereas new technologies require capital investments and additional effort in training personnel, which may be more variably adopted. Recent studies have also shown a trend toward greater use of advanced RT technologies, such as IMRT and stereotactic radiosurgery, in the last month of life, despite greater costs and scant data showing incremental clinical benefit in this context.[23] Physician variation may also be a consequence of variability in local healthcare markets and physician compensation models. For example, prior studies have shown differences in the use of IMRT among patients treated in freestanding versus hospital-based radiation facilities, those treated at self-referring versus non–self-referring practices, and those treated in regions with favorable versus unfavorable IMRT reimbursement policies, suggesting that financial factors may play a role.[24–26] In our analysis, we likewise observed a greater use of IMRT and extended fractionation at freestanding versus hospital-based facilities. On the other hand, the use of stereotactic RT was more common at hospital-based facilities, likely because of a greater need for specialized personnel and physician involvement.

Finally, patient case-mix variables such as patient age, sex, race, comorbidity score, marital status, region, rural residence, cancer type, and site of metastases influenced the use of radiation technology and extended fractionation. However, these patient factors combined accounted for a smaller portion of variations in the use of high-cost technologies and of extended fractionation compared with radiation oncologists' choices.

There are several limitations to our analysis. First, our data were limited to patients aged >65 years living in SEER surveillance areas and enrolled in fee-for-service Medicare; thus these data may not be generalizable to other populations. However, because most patients with cancer are diagnosed at age >65 years, and because fee-for-service Medicare provides insurance coverage for most Americans aged >65 years, our cohort's experience should represent the typical patterns of care for metastatic cancer, and the SEER-Medicare population has previously been shown to be representative of the general population.[27,28]

In addition, SEER-Medicare data lack the clinical details necessary to identify radiation doses, fields, and volumetric and dosimetric data, and it is possible that these factors could affect whether advanced radiation technologies are needed and used. Some patients may be treated at multiple sites, either simultaneously or sequentially. Although we excluded patients who had claims that were consistent with a second course of RT within the 90-day episode of care, we were not able to identify patients who had treatment to more than 1 site during the same radiation course, because only 1 claim is submitted per RT delivery, regardless of the number of sites treated. Moreover, although patient case-mix and treating physician explained approximately half of the observed variation in use of advanced radiation technologies, there remained substantial unexplained

Table 3. Factors (Fixed Effects) Associated With Radiation Technology and Extended Fractionation

	Extended Fractionation for EBRT		IMRT		Stereotactic RT		Extended Fractionation for Bone Metastases	
Fixed Effects	**OR (95% CI)**	***P* Value**	**OR (95% CI)**	***P* Value**	**OR (95% CI)**	***P* Value**	**OR (95% CI)**	***P* Value**
Age group, y		<.001		.005		.072		.255
66–69	Ref		Ref		Ref		Ref	
70–74	1.00 (0.92–1.09)		0.97 (0.85–1.11)		1.16 (1.01–1.32)		1.15 (0.96–1.39)	
75–79	0.99 (0.89–1.09)		1.03 (0.88–1.19)		1.09 (0.93–1.27)		1.16 (0.95–1.42)	
≥80	0.78 (0.71–0.86)		0.81 (0.70–0.94)		1.20 (1.04–1.40)		1.01 (0.83–1.22)	
Sex		.031		.371		.443		.376
Female	Ref		Ref		Ref		Ref	
Male	0.92 (0.86–0.99)		1.05 (0.94–1.18)		0.96 (0.86–1.07)		0.93 (0.79–1.09)	
Race		.372		.468		.049		.494
White	Ref		Ref		Ref		Ref	
Black	0.97 (0.85–1.11)		0.94 (0.77–1.15)		0.75 (0.59–0.96)		1.00 (0.75–1.33)	
Other	1.12 (0.94–1.34)		0.86 (0.65–1.13)		1.00 (0.78–1.28)		1.22 (0.89–1.68)	
Rural residence		.958		.549		.123		.112
No	Ref		Ref		Ref		Ref	
Yes	1.00 (0.90–1.10)		0.96 (0.84–1.10)		0.88 (0.75–1.03)		0.86 (0.72–1.04)	
State Medicaid buy-in		.014		.626		.019		.372
No	Ref		Ref		Ref		Ref	
Yes	0.88 (0.79–0.97)		0.96 (0.83–1.12)		0.82 (0.70–0.97)		0.91 (0.73–1.13)	
College education quintile[a]		.997		.345		.823		.289
1 (lowest)	Ref		Ref		Ref		Ref	
2	1.00 (0.89–1.11)		0.88 (0.75–1.04)		0.96 (0.81–1.13)		0.99 (0.81–1.22)	
3	1.01 (0.90–1.12)		0.89 (0.76–1.04)		0.99 (0.84–1.17)		1.08 (0.87–1.34)	
4	0.99 (0.88–1.11)		0.92 (0.77–1.09)		0.98 (0.82–1.17)		0.91 (0.73–1.14)	
5	0.98 (0.88–1.10)		1.00 (0.83–1.20)		1.06 (0.89–1.27)		0.86 (0.69–1.08)	
Poverty rate		.606		.146		.687		.883
Low (<10%)	Ref		Ref		Ref		Ref	
High (≥10%)	0.98 (0.91–1.05)		0.92 (0.81–1.03)		0.98 (0.87–1.10)		0.99 (0.85–1.15)	
Region		.004		.115		.010		.013
Northeast	Ref		Ref		Ref		Ref	
South	1.19 (1.02–1.40)		0.91 (0.69–1.20)		0.87 (0.65–1.17)		1.10 (0.85–1.44)	
Midwest	0.96 (0.80–1.16)		0.99 (0.71–1.38)		0.88 (0.64–1.23)		0.82 (0.61–1.10)	
West	1.22 (1.06–1.41)		1.18 (0.94–1.48)		1.28 (0.98–1.67)		1.27 (1.02–1.58)	
Marital status		<.001		.439		.580		.001
Married/Partner	Ref		Ref		Ref		Ref	
Single	0.86 (0.81–0.93)		0.96 (0.86–1.07)		1.03 (0.93–1.15)		0.79 (0.68–0.91)	
Modified CCI score		.027		.366		.421		.383
0	Ref		Ref		Ref		Ref	
1	1.00 (0.93–1.08)		0.93 (0.82–1.05)		1.07 (0.95–1.21)		0.89 (0.75–1.05)	
≥2	0.89 (0.82–0.97)		1.02 (0.90–1.16)		1.08 (0.94–1.24)		0.98 (0.82–1.17)	
Treatment location		<.001		<.001		<.001		<.001
Freestanding	Ref		Ref		Ref		Ref	
Hospital	0.74 (0.67–0.82)		0.55 (0.46–0.65)		1.66 (1.35–2.04)		0.69 (0.58–0.83)	

(continued on next page)

Table 3. Factors (Fixed Effects) Associated With Radiation Technology and Extended Fractionation (cont.)

	Extended Fractionation for EBRT		IMRT		Stereotactic RT		Extended Fractionation for Bone Metastases	
Fixed Effects	**OR (95% CI)**	***P* Value**	**OR (95% CI)**	***P* Value**	**OR (95% CI)**	***P* Value**	**OR (95% CI)**	***P* Value**
Cancer type		<.001		<.001		.001		.176
Lung	Ref		Ref		Ref		Ref	
Breast	1.45 (1.25–1.68)		0.93 (0.73–1.19)		0.80 (0.62–1.03)		1.22 (0.96–1.56)	
Prostate	1.18 (1.03–1.34)		2.21 (1.81–2.68)		0.59 (0.44–0.80)		1.18 (0.97–1.44)	
Colorectal	2.46 (2.05–2.94)		1.74 (1.42–2.13)		1.25 (0.97–1.62)		0.97 (0.53–1.75)	
Metastases at diagnosis								
Bone (yes vs no)	0.52 (0.49–0.56)	<.001	0.33 (0.29–0.38)	<.001	0.49 (0.44–0.56)	<.001	Ref	
Brain (yes vs no)	0.68 (0.62–0.74)	<.001	0.27 (0.22–0.32)	<.001	3.37 (2.94–3.86)	<.001	1.62 (1.29–2.03)	<.001
Liver (yes vs no)	0.61 (0.56–0.67)	<.001	0.61 (0.53–0.71)	<.001	0.72 (0.62–0.83)	<.001	0.64 (0.53–0.78)	<.001
Lung (yes vs no)	0.95 (0.87–1.02)	.161	0.94 (0.84–1.05)	.274	0.99 (0.88–1.12)	.907	0.92 (0.77–1.10)	.332
Year of diagnosis		<.001		<.001		<.001		<.001
2010	Ref		Ref		Ref		Ref	
2011	1.00 (0.90–1.12)		1.40 (1.17–1.67)		1.30 (1.08–1.56)		1.01 (0.80–1.27)	
2012	0.86 (0.76–0.96)		1.26 (1.03–1.54)		1.49 (1.23–1.80)		0.93 (0.74–1.16)	
2013	0.77 (0.68–0.86)		1.44 (1.19–1.75)		1.69 (1.39–2.07)		0.69 (0.54–0.87)	
2014	0.78 (0.69–0.88)		1.87 (1.54–2.27)		1.79 (1.48–2.16)		0.67 (0.54–0.85)	
2015	0.74 (0.66–0.84)		2.36 (1.94–2.87)		2.10 (1.73–2.57)		0.67 (0.53–0.85)	

The models include patient-level fixed effects and a random intercept for physicians.
Abbreviations: CCI, Charlson comorbidity index; EBRT, external-beam radiation therapy; IMRT, intensity-modulated radiation therapy; OR, odds ratio; RT, radiation therapy.
[a]Percent of persons aged ≥25 years with at least 4 years of college education in the patient's census tract.

variation in treatment, which could result not only from random variation in treatment but also from unobserved characteristics, such as the local healthcare market environment or other unobserved patient and provider characteristics.

Furthermore, it is possible that differences in the costs of radiation could be offset by a reduction in adverse effects or improvement in outcomes. For example, use of IMRT has been associated with reduction of pneumonitis in patients with lung cancer and salivary function in those with head and neck cancer treated with curative intent,[29,30] although there is no strong evidence of similar benefit in patients receiving palliative radiation. Cost-effectiveness studies of palliative radiation have shown greater cost-effectiveness with single-fraction versus multifraction radiation,[31] although there are clinical contexts in which stereotactic RT may be cost-effective compared with conventional radiation.[32,33]

An additional limitation of our analysis is that outcomes related to palliation such as pain control are not available in the claims data, and toxicities from radiation such as esophagitis may not be reliably captured in claims data unless they are severe enough to require medical treatment. Although multiple studies of radiation for bone metastases have not found extended fractionation to be beneficial, the introduction of new systemic therapies, including targeted therapies and immunotherapy that are associated with improvements in prognosis, could shift this balance, particularly in patients with oligometastatic disease. Finally, although reducing variation in use of high-cost technologies can help reduce the costs of palliative RT, these costs constitute a small proportion of overall cancer and end-of-life spending.[34,35]

Conclusions

Findings from our study support efforts to examine radiation oncologists' discretionary use of high-cost technologies. Although we have shown that variation in care is associated with differences in mean costs of palliative RT, by physician, additional work is needed to determine whether this variation in care affects patient outcomes. There are certainly situations in which use of high-cost technologies may be justified, such as for reirradiation and treatment of radioresistant tumors. Advanced and often high-cost technologies are attractive for their ability to improve accuracy and reduce toxicity from RT, but their impact on palliative endpoints has not been as well established as it has been for curative-intent RT. Furthermore, as alternative payment models for radiation oncology are implemented, including proposed episode-based payment models, we will be able to better examine the extent to which physician variation is a consequence of financial incentives versus other factors affecting physician practice, such as availability of resources and local referral and practice patterns.

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