original report An Approach to Identify Delivery of Palliative Radiation Therapy Using Health Care Claims Data: A Proof-of-Concept Application of a Visual Analytics Tool

abstract **Purpose** There is limited information on the use of data visualization tools for health services research applications. We provide a proof-of-concept application that focuses on claims-based measures of palliative radiation therapy. We investigate whether a guided, data-driven investigation contributes information for subsequent statistical analysis and algorithm development.

Methods This retrospective cohort study used linked registry and claims data on men who were diagnosed with stage IV M0 or stage IV M1b prostate cancer between 2005 and 2009, with associated claims from 2005 through 2010, and receiving radiation therapy. Preprocessing of data was accomplished by using EventFlow software to investigate longitudinal patterns in claims for radiation therapy in the 13 months after cancer diagnosis. Guided by results from EventFlow, we developed descriptive statistics to investigate the length of radiation therapy, use of bone metastasis coding, and mortality between M1b and M0 patients.

Results A total of 1,151 patients met the inclusion criteria. Taking advantage of the novel aggregation capability of EventFlow, we observed differences in the length of radiation therapy and the use of bone metastasis coding between men with (M1b) and without (M0) a diagnosis of bone metastasis. Seventy-nine percent of M1b patients received radiation for a duration ≤ 4 weeks, which suggested palliative radiation (to the bone). Seventy-six percent of M0 patients received radiation for ≥ 6 weeks, which suggested radiation to the prostate. Mortality was higher among those who received a shorter duration of radiation therapy compared with those who received a longer duration of therapy.

Conclusion Use of EventFlow, followed by statistical analysis of the linked registry and claims data, identified useful components of a claims-based measure of radiation to the bone.

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INTRODUCTION

Current trends point to the increased availability of administrative claims data for use in studying health services utilization and the cost of medical care. These data sets do not always include the measures—for example, clinical diagnosis—that are needed for analysis, and researchers will often apply algorithms or structured approaches to create claims-based measures. Development of a structured approach involves several key tasks, the first of which involves the preprocessing of data. Preprocessing consists of data visualization techniques and statistical tests to reveal patterns and relationships that will be important to incorporate in the structured approach. In this work, we are concerned with the preprocessing

stage, about which there is limited guidance in the health services literature.

Data visualization and statistical analyses that are involved in the preprocessing stage provide unique and complementary information. Statistical analyses provide metrics, uncertainty, and statistical significance, whereas data visualization provides context, accountability, and, most notably, reveals previously unknown patterns and components that are required for creating structured approaches.¹⁻³ Failure to apply proper preprocessing techniques can result either in the loss of useful information or the incorporation of incorrect information.⁴

Uses of data visualization and statistical analyses in the development of measures are usefully

Eberechukwu Onukwugha
Jinani Jayasekera
James Gardner
Sana Malik
C. Daniel Mullins
Arif Hussain
Jay P. Ciezki
Chandana A. Reddy
Brian Seal
Adriana Valderrama
Young Kwok

Author affiliations and support information (if applicable) appear at the end of this article.

Corresponding author: Eberechukwu Onukwugha, PhD, Pharmaceutical Health Services Research Department, University of Maryland School of Pharmacy, 220 Arch St, Baltimore, MD 21201; e-mail: eonukwug@rx.umaryland.edu.

Fig 1. (A) Patients with stage IV M1b prostate cancer (PCa), with bone metastasis events within 30 days before PCa diagnosis to 1 year postdiagnosis, aligned at the date of first radiation episode. (B) Patients with stage IV M1b PCa, with radiation episodes split by episode duration—episodes within 30 days before PCa diagnosis to 1 year postdiagnosis, excluding bone metastasis episodes.

illustrated by example. We employed a proof-of-concept application of data visualization techniques to the development of a claims-based measure of treatment receipt among men who were diagnosed with metastatic prostate cancer (PCa). Metastatic PCa has a poor prognosis, and death from PCa is almost always caused by distant metastases.⁵ A high percentage of men with metastatic PCa (70% to 80%) feature bone involvement,⁶ which puts these patients at increased risk of a variety of skeletal-related events (SREs), including pathologic fracture, bone surgery, radiation to the bone (RtB), and spinal cord compression.^{6,7} RtB is reported to be the most common SRE,⁸ and previous claims studies have used billing and/or encounter codes in claims to identify RtB.^{6,8} The validity of using claims data to characterize these conditions can be questioned, as the International Classification of Diseases, Ninth Revision (ICD-9) billing and/or encounter codes in Medicare claims do not

differentiate between receipt of radiation to the prostate gland and RtB.⁸

There has been limited investigation of the possibilities for enhancing the precision of that radiation codes that are available in claims data by incorporating clinical characteristics associated with radiation therapy that have not been previously explored. For example, the duration of radiation therapy that targets the bone tends to be shorter than the duration of radiation to prostate tissue, where RtB ranges between 1 day and 30 days and radiation to the prostate tissue spans 8 weeks.⁹ Prior work has demonstrated that the use of data visualization to inform the radiation component of the SRE measure has an impact on conclusions regarding the mortality impact of SREs.¹⁰ The objectives of the current study are two-fold: present steps and techniques that are involved in preprocessing Medicare administrative data, and apply those techniques to identify the components that are required for developing a measure for RtB in metastatic PCa.

METHODS

Data Source

Information on PCa stage at diagnosis was collected by using the National Cancer Institute SEER database.¹¹ SEER consists of a national cancer surveillance network of 17 regional cancer registries that cover approximately 28% of the US population.¹¹ Each registry records all diagnosed cancers within its region and detailed information on demographic characteristics, date of cancer diagnosis, cancer site and histology, and initial cancer therapies.¹¹ Medicare enrollment and claims files were linked to SEER data at the individual level to record medical service utilization by Medicare beneficiaries before and after their cancer diagnosis. Claims data that were available for this study included claims from 2004 through 2010 for men who were diagnosed with stage IV M0 and stage IV M1b PCa between 2005 and 2009. This study received institutional review board approval (#HP-00049426).

Study Population

The study sample included men age ≥ 66 years who were diagnosed with metastatic—M0 and M1b—PCa between 2005 and 2009, provided Medicare claims from 2004 to 2010, and received radiation therapy within the first 13 months of

Fig 1. (Continued). (C) Patients with stage IV MO PCa, with bone metastasis events within 30 days before PCa diagnosis to 1 year postdiagnosis, aligned at the date of first radiation episode. (D) Patients with stage IV MO PCa, with radiation episodes split by episode duration—episodes within 30 days before diagnosis to 1 year postdiagnosis, excluding bone metastasis episodes.

follow-up, including 30 days before PCa diagnosis. Patients were required to have continuous fee-for-service Medicare Parts A and B coverage in the 13 months before cancer diagnosis. Patients who were enrolled in a Medicare Advantage plan during this 13-month period were excluded because their Medicare claims data were incomplete. Patients with a history of cancer within 5 years before diagnosis of PCa, an unknown PCa diagnosis month, or a diagnosis of PCa at autopsy were also excluded. We restricted the follow-up period to 13 months—that is, diagnosis month plus 12 months—to reduce the likelihood that MO patients would develop metastasis during the follow-up period.

Candidate Variables for Components of the Measure

The following variables were identified by using diagnosis codes (International Classification of Diseases, Ninth Revision [ICD-9-CM]) and

procedure codes from inpatient and/or outpatient claims:

1. Receipt of external beam radiation therapy, including intensity-modulated radiotherapy and stereotactic body radiation therapy, and radiopharmaceutical therapy. Radiation therapy episodes were grouped into five categories according to the duration of the episode ($0 \leq 2$ weeks, $2 \leq 4$ weeks, $4 \leq 6$ weeks, $6 \leq 8$ weeks, and > 8 weeks).
2. Bone metastasis: Claims with a bone metastasis (BM) diagnosis code.
3. Management: Visits made to radiation and/or nuclear medicine specialists and the number of claims for the management of radiation.
4. Bone scans.
5. Other scans: X-rays, magnetic resonance imaging, radiologic examination, computed tomography, positron emission tomography imaging, and diagnostic radiopharmaceuticals.

The list of ICD-9 and procedure codes is available upon request.

Data Visualization and Analysis—EventFlow Software

We used the EventFlow visualization tool (www.cs.umd.edu/hcil/eventflow), which supports exploratory, visual analyses of temporal event sequences.² It provides an overview of all sequences of events to obtain an understanding of the temporal features and the prevalence of the patterns observed in a cohort of patients. EventFlow is a research prototype that was developed at the Human-Computer Interaction Laboratory of the University of Maryland (College Park, MD). The search-and-replace feature of EventFlow, combined with rich manipulations, enable users to transform their data sets to detect missing events, reveal unexpected sequences, and identify subgroups that require additional examination in the data. Per the data use agreement, EventFlow was customized to only display events and event sequences that occurred in ≥ 11 patients.

SEER records were used to create a cohort file that was suitable for identification and classification by EventFlow. Medicare claims were used to identify single-day and episode events. Single-day events

Table 1. Patient and Disease Characteristics of Radiation Therapy Recipients With Stage IV M0 and M1b Prostate Cancer Diagnosed in 2005 to 2009

Characteristic	Full Sample (N = 1,151)		M1b (n = 742) ^a		M0 (n = 409) ^b	P
	No.	% ^c	% ^c	% ^c	% ^c	
Demographic						.12
Race and ethnicity						
White non-Hispanic	971	84.4	82.9	87.0		
African American non-Hispanic	118	10.3	11.6	7.8		
Other	62	5.4	5.5	5.1		
Age, years						< .01
66-69	292	25.4	18.5	37.9		
70-74	277	24.1	21.0	29.6		
75-79	250	21.7	23.7	18.1		
80-84	176	15.3	18.9	8.8		
≥ 85	156	13.6	17.9	5.6		
Married	757	65.8	62.1	72.4		< .01
Urban location	1,041	90.4	91.0	90.2		.49
Clinical						
Skeletal-related events						
Radiation with a bone metastasis diagnosis	768	66.7	91.1	22.5		< .01
Spinal cord compression ^d	125	10.9	13.3	6.4		< .01
Pathologic fracture ^e	175	15.2	20.8	5.1		< .01
Bone surgery only ^f	95	8.2	10.8	3.7		< .01
Poorly differentiated tumor (at diagnosis) ^g	820	71.2	62.8	86.6		< .01
Charlson comorbidity index (prediagnosis) ^h						< .01
0	701	60.9	56.6	68.7		
1	225	19.6	19.1	20.3		
≥ 2	161	14.0	16.7	> 3.0 ⁱ		
Missing	64	5.6	7.6	< 3.0 ⁱ		
Charlson comorbidity index (postdiagnosis) ^j						< .01
0	460	40.0	31.7	55.0		
1	227	19.7	17.5	23.7		
≥ 2	191	16.6	18.2	13.7		
Missing	273	23.7	32.6	7.6		
Performance status proxy (postdiagnosis) ^j	762	66.2	68.7	61.6		.02
Hospitalization	728	63.2	64.6	60.9		.22
Skilled nursing facility use	197	17.1	23.9	4.9		< .01
Oxygen and related supplies	106	9.2	11.1	5.9		< .01

(Continued on following page)

had a start date and included events, such as visiting a physician, having a medical procedure, or end of study. Episode events had both a start date and an end date and included episodes, such as a

hospital stay, prescribed medication, or prolonged medical treatment. Preparing both of these events for EventFlow required that events be represented by rows and that each event contain, at most, five

Table 1. Patient and Disease Characteristics of Radiation Therapy Recipients With Stage IV M0 and M1b Prostate Cancer Diagnosed in 2005 to 2009 (Continued)

Characteristic	Full Sample (N = 1,151)		M1b (n = 742) ^a	M0 (n = 409) ^b	P
	No.	% ^c	% ^c	% ^c	
Wheelchair	130	11.3	15.5	3.7	< .01
Walking aid	126	11.0	15.2	3.2	< .01
Prostate cancer death	349	79.9	80.9	72.0	.14

NOTE. Radiation treatment could consist of receipt of external beam radiation therapy, radiopharmaceutical therapy, intensity-modulated radiotherapy, or stereotactic radiosurgery from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^aDiagnosed with bone metastasis according to SEER data (ie, stage IV M1b).

^bDiagnosed with stage IV M0 prostate cancer.

^cColumn percentage is calculated as the ratio of the frequency count for a single cell to the total frequency count for the column that contains the cell. The ratio is represented as a percentage (eg, % for white non-Hispanics in the full sample = (1,261/1,491) × 100 = 84.6%).

^dSpinal cord compression with or without pathologic fracture/surgery performed on the same bone within 183 days of the spinal cord compression event. Events captured from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^ePathologic fracture without spinal cord compression events, and with or without surgery performed on the same bone surgery within 90 or 183 days of the pathologic fracture event. Events captured from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^fBone surgery without pathologic fracture or spinal cord compression events. Events captured from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^gIncludes grade 3 malignant neoplasms according to histologic grading and differentiation codes used by SEER.

^hOne year prediagnosis.

ⁱNot reported because of small cell size (≤10), per data use agreement.

^jOne year postdiagnosis.

data elements: patient ID, event category, start date, end date, and attribute. The fifth data item was optional and provided more details about the event—for example, the reason the patient left the study, such as lost to follow-up, survived to the end of the study, or died. Unique patient IDs linked all events for the same patient. EventFlow output was reviewed by study team members with differing specializations, including health services research, radiation oncology, medical oncology, statistics, and computer science.

Statistical Tests

We produced descriptive statistics and group comparisons to examine the demographic and clinical characteristics of the sample. We calculated the sample estimates for the time-to-first radiation episode, time-to-first radiation episode with a BM diagnosis, the number of management and diagnostic claims, and claims with BM diagnosis for the full sample and subgroups stratified by stage IV M1b and M0 diagnosis.

Predictive Validity: Outcomes

Duration of RtB tends to be shorter than that of radiation to the prostate gland, and a higher

proportion of patients who die from PCa feature bone involvement.^{6,12} To assess predictive validity, we investigated whether there was a positive association between RtB and all-cause mortality. Bivariable associations between measure components and mortality were explored by using χ^2 tests.

Statistical analyses were performed using SAS (SAS/STAT User's Guide, Version 9.2; SAS Institute, Cary, NC) and STATA software (version 10.0; STATA, College Station, TX).

RESULTS

EventFlow Analysis

Overall, 1,151 patients who met inclusion criteria were identified for analysis. We used EventFlow to explore the patterns of claims that had a diagnosis of BM 30 days before and 1 year after the patient's first radiation episode as well as the duration of radiation episodes. [Figure 1A](#) indicates that the majority (approximately 82%) of patients with M1b PCa had at least one BM event after their first radiation episode and that only approximately 10% of these patients did not have a BM event within 30 days before or 1 year after their first radiation episode. [Figure 1B](#) shows the duration of the radiation episode for

Table 2. Time-to-Event (in days) and Counts: Estimated Parameters Among Radiation Therapy Recipients With Stage IV M0 and M1b Prostate Cancer Diagnosed in 2005 to 2009 (N = 1,151)

Variable	No.	Mean	SD	Median	Minimum	Maximum
All						
Time to first radiation episode, days	1,151	132	94	109	−27	365
Time to first radiation episode with a bone metastasis diagnosis, days	768	119	98	83	−27	365
No. of physician visits ^a	1,151	14	12	12	0	67
Diagnostics						
Bone scans ^b	1,151	2	1	1	0	10
Other ^c	1,151	11	8	9	0	94
Claims with bone metastasis diagnosis ^d	1,151	19	25	11	0	128
M1b ^e						
Time to first radiation episode, days	742	115	97	80	−27	365
Time to first radiation episode with a bone metastasis diagnosis, days	676	113	99	78	−27	365
Management ^a	742	10	10	8	0	64
Diagnostics						
Bone scan ^b	742	2	1	2	0	10
Other ^c	742	12	8	10	0	76
Claims with bone metastasis diagnosis ^d	742	28	26	21	0	128
M0 ^f						
Time to first radiation episode, days	409	162	80	149	−27	353
Time to first radiation episode with a bone metastasis diagnosis, days	92	159	84	146	7	343
Management ^a	409	19	13	17	0	67
Diagnostics						
Bone scan ^b	409	1	1	1	0	6
Other ^c	409	10	9	7	0	94
Claims with bone metastasis diagnosis ^d	409	4	11	0	0	79

NOTE. Radiation treatment could consist of receipt of external beam radiation therapy, radiopharmaceutical therapy, intensity-modulated radiotherapy, or stereotactic radiosurgery 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^aCount of visit for the management of radiation or visits to radiation/nuclear medicine specialists per patient from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^bCount of bone scans per patient from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^cCount of scans per patient from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up. Scans include x-rays, magnetic resonance imaging, radiologic examination, computed tomography, positron emission tomography imaging, and provision of diagnostic radiopharmaceuticals.

^dCount of claims with a bone metastasis diagnosis on the claim per patient from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^eDiagnosed with bone metastasis according to SEER data.

^fDiagnosed with stage IV M0 prostate cancer.

patients with M1b PCa. [Figure 1C](#) provides the same information as [Figure 1A](#) for patients with M0 PCa. [Figure 1D](#) provides the same information as [Figure 1B](#) for patients with M0 PCa.

If we compare [Figure 1A](#) with [Figure 1C](#), only about 13% of patients in the M0 group had a BM

event either 30 days before or 1 year after their first radiation episode. In [Figure 1B](#), the majority (approximately 75%) of patients in the M1b group who had a first radiation episode had it for a duration of ≤ 4 weeks (dark blue or maroon), which is more likely a regimen for palliative care (RtB). From [Figure 1D](#), the first radiation episode was

≥ 6 weeks (blue or light moss green) for the majority (approximately 76%) of men who were diagnosed with M0 PCa and who received radiation within the follow-up period. Longer duration of radiation is more likely to be for the definitive treatment of PCa—that is, radiation to the prostate.

Among M1b patients (Fig 1A), the requirement of a BM claim before the first radiation claim is correlated with the requirement for a BM claim on or after the first radiation claim. In addition, the requirement of a BM diagnosis code on the radiation claim is likely to include the majority of first radiation claims among M1b patients and exclude all of the first radiation claims among M0 patients. This finding has implications for prior claims-based studies as they typically required a BM diagnosis code before the first radiation claim and did not require a BM code on the radiation claim.

Statistical Analysis

Table 1 lists the baseline characteristics and bivariable associations between patient characteristics and SREs among patients with stage IV M1b and M0 PCa. Among patients with SREs, 67% had a radiation episode with BM diagnosis, 11% experienced spinal cord compression only, 15% experienced pathologic fracture only, and 8% underwent bone surgery only during follow-up. The percentage of patients with stage IV M1b PCa who received radiation with a BM diagnosis on the claim was significantly higher compared with those with stage IV M0 PCa (91% v 23%).

Descriptive statistical analysis (Table 2) demonstrated that patients received the first radiation episode within approximately 4 months of PCa diagnosis (any radiation, 132 days [standard deviation {SD} = 94]; and any radiation with BM, 119 days [SD = 98]). Time-to-first radiation episode was shorter among M1b patients compared with M0 patients. The average number of claims with a BM diagnosis among M1b patients (mean, 28 [SD = 26]) was higher compared with M0 patients (mean, 4 [SD = 11]).

Table 3 indicates that a statistically significantly higher percentage of patients with stage IV M1b PCa (47.2% and 32.5%) received shorter lengths (0 to 2 weeks and 2 to 4 weeks) of radiation episodes compared with patients with stage IV M0

disease (7.3% and 5.6%), respectively, whereas a statistically significantly higher percentage of patients with stage IV M0 PCa (38.6% and 36.9%) received longer lengths (6 to 8 weeks and > 8 weeks) of radiation episodes compared with patients with stage IV M1b disease (5.5% and 6.6%), respectively. In addition, a statistically significantly higher proportion of patients with stage IV M0 PCa had radiation claims without BM codes compared with patients with stage IV M1b disease (77.5% v 8.9%).

Predictive Validity: Outcomes

A higher proportion of patients who received a shorter duration of radiation died during follow-up, whereas a higher proportion of patients who received a longer duration of radiation remained alive at the end of follow-up (Table 4). These results were consistent across both M1b and M0 patients.

DISCUSSION

EventFlow provides a visually appealing method for examining patterns of patterns—for example, the distribution of length of radiation therapy over time for a given patient and then across patients. Visualizing these patterns during the preprocessing stage provides important, empirical information with which to guide statistical analysis. Methods for preprocessing data to generate new information and learn about the data set are not new¹³; however, there are limited studies, to date, that illustrate the use of data visualization tools for investigating health services utilization data. The contribution of this study is both conceptual and empirical. On the conceptual side, it illustrates how a guided, data-driven investigation can uncover patterns for use in subsequent statistical analysis. On the empirical side, it illustrates how clinical knowledge, combined with data visualization capabilities, can efficiently identify patterns that can be used to compare candidate claims-based measures with the goal of improving measures that are used to describe clinical outcomes.

Use of data visualization establishes a useful paradigm with which to enhance the analysis of longitudinal patient-related information to better understand clinical outcomes, including treatment duration. In this study, preprocessing data by using EventFlow indicated that shorter-length episodes were more common in M1b patients

Table 3. Patterns of the First Radiation Episode and Health Services Utilization Among Radiation Therapy Recipients With Stage IV M0 and M1b Prostate Cancer Diagnosed in 2005 to 2009

Variable	Full Sample (N = 1,151)		M1b (n = 742) ^a	M0 (n = 409) ^b	P
	No.	%	%	%	
Length of episode, weeks					< .01
0-2	380	33.0	47.2	7.3	
2-4	264	22.9	32.5	5.6	
4-6	108	9.4	8.2	11.5	
6-8	199	17.3	5.5	38.6	
> 8	200	17.4	6.6	36.9	
Management ^c					< .01
No visits	91	7.9	8.8	6.4	
1-10	441	38.3	53.2	11.3	
11-20	400	34.8	26.6	49.6	
> 20	219	19.0	11.5	32.8	
Diagnostics					
Bone scan ^d					< .01
No bone scan	63	5.5	5.4	> 3.0 ^e	
1-2	855	74.3	69.5	82.9	
3-5	215	18.7	22.8	11.2	
> 5	18	1.6	2.3	< 3.0 ^e	
Other ^f					< .01
1-10	688	59.8	55.8	67.0	
11-20	326	28.3	31.8	22.0	
> 20	135	11.7	12.3	10.8	
Claims with bone metastasis diagnosis ^g					< .01
No claims	383	33.3	8.9	77.5	
1-10	183	15.9	18.3	11.5	
11-20	170	14.8	20.9	3.7	
> 20	415	36.1	51.9	7.3	

NOTE. Radiation treatment could consist of receipt of external beam radiation therapy, radiopharmaceutical therapy, intensity-modulated radiotherapy, or stereotactic radiosurgery 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^aDiagnosed with bone metastasis according to SEER data.

^bDiagnosed with stage IV M0 prostate cancer.

^cCount of visit for the management of radiation or visits to radiation/nuclear medicine specialists per patient from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^dFrequency of bone scans per patient from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^eNot reported because of small cell size (≤ 10), per data use agreement.

^fFrequency of scans per patient from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up. Scans include x-rays, magnetic resonance imaging, radiologic examination, computed tomography, positron emission tomography imaging, and provision of diagnostic radiopharmaceuticals.

^gFrequency of claims with a bone metastasis diagnosis on the claim per patient from 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

compared with M0 patients and that the shorter-length episodes in M1b patients were not a result of early mortality. We then used traditional statistical methods to describe the differences between M0 and M1b groups. Prior studies^{6,8} have required that claims before the radiation therapy claim include a BM diagnosis code,

but have not required that the radiation therapy claim include a BM diagnosis code. Among M1b patients, we found that the requirement for a prior BM code is unlikely to yield additional occurrences of RtB for M1b patients. Among M0 patients with a first radiation therapy claim that was preceded by a BM claim, there was

Table 4. Predictive Validity Assessment of the Duration of the First Radiation^a Episode Among Radiation Therapy Recipients With Stage IV M0 and M1b Prostate Cancer Diagnosed in 2005 to 2009

Variable	Full Sample (N = 1,151)		Alive at the End of Follow-Up ^a	Died During Follow-Up ^b
	No.	%	%	%
All cause death ^b				
M1b (length of episode), weeks ^c				
Total	742	100	(n = 234)	(n = 508)
0-2	350	47.2	35.9	52.4
2-4	241	32.5	23.9	36.4
4-6	61	8.2	13.3	5.9
6-8	41	5.5	11.5	2.8
> 8	49	6.6	15.4	2.6
M0 (length of episode), weeks ^d				
Total	409	100	(n = 331)	(n = 78)
0-2	30	7.3	> 4.0 ^e	15.4
2-4	23	5.6	< 4.0 ^e	16.7
4-6	47	11.5	11.2	12.8
6-8	158	38.6	41.1	28.2
> 8	151	36.9	39.3	26.9

NOTE. Radiation treatment could consist of receipt of external beam radiation therapy, radiopharmaceutical therapy, intensity-modulated radiotherapy, or stereotactic radiosurgery 1 month before stage IV prostate cancer diagnosis through 1 year of follow-up.

^aAlive as of December 31, 2010.

^bDied of any cause per Medicare records during the observation period ending in December 31, 2010.

^cDiagnosed with bone metastasis according to SEER data.

^dDiagnosed with stage IV M0 prostate cancer.

^eNot reported because of small cell size (≤ 10), per data use agreement.

no BM code on the majority of claims that were made within 1 year after the first radiation claim, and, thus, the radiation therapy may not have been delivered to the bone. Defining RtB on the basis of the presence of a prior BM code would include these claims from the M0 group, even though many of these M0 claims will not represent RtB. Requiring a BM code on or after the radiation therapy claim is preferred to requiring a prior BM claim because it would not change the claims identified from the M1b group, but it would exclude claims from the M0 group that are not likely to have represented RtB. Last, the focus on BM coding—presumably to establish underlying metastasis to the bone—assumes that the presence of the BM code is a proxy for a clinical diagnosis of BM; however, the BM code that is available in claims data is not a reliable indicator of a BM diagnosis,^{14,15} and, thus, a

more stringent requirement, such as that proposed here, would be needed when using the BM code.

Costs could potentially help to identify the course of therapy using the assumption that the costs of curative treatment are higher than the costs of palliative therapy. Prior research using SEER-Medicare data has indicated that the average cost (SE) per course of radiation therapy was \$4,950 (\$325)¹⁶ in the palliative care setting, and the median cost (interquartile range) for a course of radiotherapy was \$18,000 (\$11,300 to \$25,500)¹⁷ in the nonmetastatic setting; however, to the extent that researchers who use claims data will define a course of therapy before estimating the associated costs, any insight regarding the appropriate components of a claims-based measure of palliative radiation will be useful. In addition, it will be important to use the software in a setting that requires multiple interactions—for example, among patients with breast cancer who receive second-line therapy.

This study uses ICD-9 codes, which do not confirm the site of delivery of radiation. The new ICD-10 coding system, in use since October 1, 2015, includes codes that identify the receipt of palliative radiation—that is, DP00-DPOC; DPY0-DPYC. Despite the availability of the new coding system, fundamental concerns with the use of billing codes remain, because ICD-10 codes may omit critical features for identifying clinical diagnoses and treatment, and the introduction of ICD-10 does not address concerns with the validity of using billing codes. In the spirit of a proof of concept, this work illustrates how clinical input can be used to design informative visual displays to guide subsequent statistical analysis and the development of measures—to be validated—when billing codes omit critical features. The development of claims-based measures is a relevant exercise, given that researchers will continue to use claims data for health services research. It will be important to identify systematic, reproducible approaches with which to develop claims-based measures.

This study has a few limitations. Diagnosis of BM that is available from the SEER registry is not validated. We selected patients who were diagnosed in 2005 onwards and excluded 2004, the year in which SEER introduced a measure to indicate a diagnosis of

BM. Whereas the M1b measure has not been validated, the information from SEER regarding the diagnosis of M1 disease is considered to be reliable. Conclusions drawn from the application of EventFlow are not expected to be sensitive to misclassification as a result of errors in the substage—that is, M1b—classification. The study investigates health services utilization among a group of older men who were diagnosed with nonmetastatic and metastatic (BM) PCa. The timing and nature of radiation therapy delivered to younger men who are diagnosed with PCa may result in a different set of conclusions.

In conclusion, data visualization tools and techniques can play an important role in analyzing available evidence to discover useful measures for developing a claims-based measure when the available billing codes in the claims data are not sufficient. We illustrate how a guided, data-driven investigation can yield actionable information for use in subsequent statistical analysis. Future studies can build on these findings to validate claims-based measures of RtB.

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AUTHOR CONTRIBUTIONS

Conception and design: Eberechukwu Onukwugha, C. Daniel Mullins, Arif Hussain, Jay P. Ciezki, Brian Seal, Adriana Valderrama

Financial support: Brian Seal

Administrative support: Eberechukwu Onukwugha

Provision of study materials or patients: Eberechukwu Onukwugha

Collection and assembly of data: Eberechukwu Onukwugha, James Gardner, Jinani Jayasekera

Data analysis and interpretation: Eberechukwu Onukwugha, Jinani Jayasekera, Sana Malik, Arif Hussain, Chandana A. Reddy, Brian Seal, Adriana Valderrama, Young Kwok

Manuscript writing: All authors

Final approval of manuscript: All authors

Accountable for all aspects of the work: All authors

AUTHORS' DISCLOSURES OF POTENTIAL CONFLICTS OF INTEREST

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Eberechukwu Onukwugha

Research Funding: Bayer, Takeda, Pfizer

Jinani Jayasekera

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James Gardner

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Sana Malik

Employment: Green Medical Network Group, Mid-America Radiology (I)

Stock and Other Ownership Interests: Mid-America Radiology (I), Green Medical Network Group (I)

C. Daniel Mullins

Honoraria: Bayer, Novartis, Pfizer, Regeneron, Sanofi

Consulting or Advisory Role: Bayer, Pfizer, Regeneron, Sanofi

Speakers' Bureau: Bayer, Pfizer

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Arif Hussain

Consulting or Advisory Role: Novartis, AstraZeneca, Bayer, Bristol-Myers Squibb

Research Funding: Sotio, Merck, Bayer, Agensys, Clovis Oncology, Cerulean Pharma

Jay P. Ciezki

Other Relationship: American Society for Radiation Oncology

Chandana A. Reddy

Other Relationship: International Journal of Radiation Oncology Biology Physics

Brian Seal

Employment: AstraZeneca, Takeda

Stock and Other Ownership Interests: Takeda

Adriana Valderrama

Employment: Bayer Healthcare

Young Kwok

No relationship to disclose

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Affiliations

Eberechukwu Onukwugha, **Jinani Jayasekera**, **James Gardner**, **C. Daniel Mullins**, **Arif Hussain**, and **Young Kwok**, University of Maryland; **Arif Hussain**, Veterans Affairs Medical Center, Baltimore; **Sana Malik**, University of Maryland, College Park, MD; **Jay P. Ciezki** and **Chandana A. Reddy**, Cleveland Clinic Foundation, Cleveland, OH; and **Brian Seal** and **Adriana Valderrama**, Bayer HealthCare Pharmaceuticals, Pine Brook, NJ.

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