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Cancer-related Imaging in the Veterans Affairs Health Care System versus Medicare: Does a System with Lower Use Exhibit Less Geographic Variation?

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Abstract

Background—Geographic variations in use of medical services have been interpreted as indirect evidence of wasteful care. Less overuse of services, however, may not be reliably associated with less geographic variation.

Objective—To compare average use and geographic variation in use of cancer-related imaging between fee-for-service Medicare and the Department of Veterans Affairs (VA) health care system.

Design—Observational analysis of cancer-related imaging from 2003–2005, using Medicare and VA utilization data linked to cancer registry data. We used multilevel models to estimate mean differences in annual imaging use between cohorts of Medicare and VA patients within geographic areas and variation in use across areas for each cohort, adjusting for sociodemographic and tumor characteristics.

Setting—40 hospital referral regions.

Patients—Older men with lung, colorectal, or prostate cancer, including 34,475 traditional Medicare beneficiaries (Medicare cohort) and 6,835 VA patients (VA cohort).

Measurements—1) Per-patient count of imaging studies for which lung, colorectal, or prostate cancer was the primary diagnosis (each study weighted by a standardized price); 2) a direct measure of overuse—advanced imaging for prostate cancer at low risk of metastasis.

Results—Adjusted annual use of cancer-related imaging was lower in the VA cohort than the Medicare cohort (price-weighted count, \$197 vs. \$379/patient; $P < 0.001$), as was annual use of

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Reproducible Research Statement:

Study protocol: available upon request from Dr. McWilliams (email, mcwilliams@hcp.med.harvard.edu)

Statistical code: available upon request from Dr. McWilliams (email, mcwilliams@hcp.med.harvard.edu)

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advanced imaging for prostate cancer at low risk of metastasis (\$41 vs. \$117/patient; $P < 0.001$). Geographic variation in cancer-related imaging use was similar in magnitude in the VA and Medicare cohorts.

Limitations—Observational study design.

Conclusions—Use of cancer-related imaging was lower in the VA health care system than in fee-for-service Medicare, but lower use was not associated with less geographic variation. Geographic variation in service use may not be a reliable indicator of the extent of overuse.

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Keywords

delivery of health care; health care costs; quality of health care; Medicare; United States Department of Veterans Affairs; diagnostic imaging; neoplasms

Geographic variations in use of medical care that are neither explained by patient characteristics nor associated with better outcomes have been interpreted as evidence of considerable waste in the U.S. health care system.(1,2) A recent Institute of Medicine study, however, concluded that policies targeting high-use areas may not effectively foster more efficient care even if they reduce geographic variation.(3–5) Because specific instances of overuse are challenging to measure directly,(6,7) geographic comparisons of risk-adjusted service use may nevertheless remain an appealing indirect approach to gauging the extent of wasteful practices. Thus, an important question not directly addressed by the Institute of Medicine study is whether a health care system achieving less overuse should necessarily exhibit less variation. In other words, is geographic variation in service use in a system a reliable correlate of the amount of overuse in that system?

To address this question, we compared use of cancer-related imaging in traditional fee-for-service Medicare and the Department of Veterans Affairs (VA) health care system—an instructive test case for several reasons. Since its transformation in the 1990s, the VA health care system has emphasized features of payment and delivery systems currently encouraged by Medicare, including accountability, integrated care delivery, quality measurement, performance incentives, and global budgets.(8–13) The VA health care system generally performs as well or better than Medicare on measures of cancer care quality,(14,15) consistent with comparisons of other quality measures and outcomes between VA and non-VA patients.(16–20) Thus, evidence of lower spending on cancer care in the VA system, particularly on frequently overused services, would suggest more efficient care. Use of advanced imaging for cancer patients has grown over recent decades and is a major focus of the American Society of Clinical Oncology’s contribution to the American Board of Internal Medicine Foundation’s Choosing Wisely list of common practices not supported by current evidence.(21–24) Finally, cancer care may be more concentrated within the VA than other types of care,(25–27) thereby supporting clearer distinctions in system performance between the VA and Medicare.

Using 2003–2005 Medicare claims and VA utilization data linked to cancer registry data for older men with lung, colorectal, or prostate cancer, we tested whether use of cancer-related imaging was lower for VA patients than for traditional Medicare beneficiaries and, if so, whether lower average use was associated with less geographic variation. Drawing from the Choosing Wisely recommendations,(24) we also compared the two systems' performance on a direct measure of cancer imaging overuse.

METHODS

Study Cohorts and Data Sources

We studied men older than 65 years with lung, colorectal, or prostate cancer first diagnosed in 2003–2004. Patients were identified from the VA Central Cancer Registry (herein called the VA cohort) or the Surveillance, Epidemiology, and End Results (SEER) Program of the National Cancer Institute (the Medicare cohort).

The VA Central Cancer Registry collects uniformly reported information on demographic and tumor characteristics for all VA patients receiving a diagnosis of, or first course of treatment for, an invasive cancer at a VA medical center. The SEER population-based cancer registries collect similar information for incident cancer patients in areas covering 28% of the U.S. population.(28) For the VA cohort, we obtained linked Veterans Health Administration data on health care utilization and Medicare enrollment and claims data through 2005, as described previously.(14,29) For the Medicare cohort, we obtained linked Medicare enrollment files and claims through 2005.(30) For both cohorts, we assessed vital status through 2005 via National Death Index linkages.

We limited analyses to 40 hospital referral regions (HRRs) with complete or partial coverage by cancer registries in the SEER program, 1 VA medical center, and 20 person-years of data both for the Medicare and VA cohort. The 40 HRRs covered 22% of the Medicare population in 2005(31) and spanned 23 states (Appendix Table 1). We excluded patients from both cohorts who were enrolled in Medicare managed care plans in the year before diagnosis, and further restricted the Medicare cohort to those continuously enrolled in Medicare Parts A and B in that year, so that pre-existing comorbid conditions could be assessed using the Klabunde modification of the Charlson Comorbidity Index.(32,33) During the 2003–2005 study period, we excluded person-years in which patients in either cohort were enrolled in Medicare managed care plans. Finally, we excluded a small number (0.6%) of Medicare and VA patients with cancer diagnosed after death or with no utilization data from 45 days before through 195 days after diagnosis (suggesting inaccurate linkage). (14,29)

For both cohorts, age, race/ethnicity, marital status, cancer type, stage, grade, and prior cancer history were ascertained from medical records by tumor registrars. We obtained ZIP code-level sociodemographic information from the 2000 U.S. Census. The Harvard Medical School Committee on Human Studies approved this study.

Cancer-related Imaging

We focused on cancer-related imaging—defined as imaging studies for which lung, colorectal, or prostate cancer was listed as the primary diagnosis (Appendix Table 2)—because we expected cancer-related imaging for VA patients diagnosed at VA facilities to be more confined to the VA system than imaging in general.⁽²⁷⁾ We analyzed total use of imaging studies (i.e., regardless of diagnosis) in a supplemental analysis that addressed potential differences in coding practices between VA and non-VA providers but was subject to greater dual use of imaging in both systems (Appendix).

For each patient, we assessed annual use of imaging from 2003 through 2005 as follows. We identified Current Procedural Terminology (CPT) codes that accounted for >95% of imaging services recorded in Medicare claims and VA utilization data in 2005 (Appendix).⁽³⁴⁾ We excluded ancillary services (e.g., contrast administration) that may be billed separately (see Appendix Table 3 for final list of 197 imaging CPT codes included). From Medicare claims, we calculated a national standardized price for each CPT code equal to the national mean payment for each imaging study, covering both professional and technical components (see Appendix for details). For each patient in each cohort, we then summed imaging studies, weighting each study by its national standardized price and removing duplicate references to the same study (i.e., same patient, CPT code, and date of service). These price-weighted counts are expressed in dollars but measure utilization (greater use of one study or use of a more costly study) and are unaffected by geographic variation in prices.

For the Medicare cohort, we summed imaging studies in Carrier and Outpatient claims files covering both inpatient and outpatient imaging. For the VA cohort, we summed imaging studies in Decision Support System National Data Extract files covering inpatient and outpatient care from VA providers, Fee Basis files covering contracted care from non-VA providers, and Medicare Carrier and Outpatient claims files covering Medicare-reimbursed care from non-VA providers.^(35–37) Therefore, price-weighted utilization counts captured imaging outside of the VA system for Medicare beneficiaries in the VA cohort but not imaging in the VA system for eligible veterans in the Medicare cohort (we could not link the Medicare cohort with VA data). To assess the influence on our results of dual use of imaging in both Medicare and VA systems by patients in either cohort, we conducted sensitivity analyses excluding patients from the Medicare cohort who were eligible for VA health benefits and patients from the VA cohort who received 1 imaging study reimbursed by Medicare (Appendix). Results after these exclusions supported our main conclusions.

Advanced Imaging for Prostate Cancer with Low Risk of Metastasis

We created 1 direct measure of low-value imaging based on the American Society of Clinical Oncology's Choosing Wisely recommendation against using advanced imaging in the staging or routine follow-up care of low-grade prostate cancer with low risk of metastasis.⁽²⁴⁾ Specifically, we used registry data to identify prostate cancer patients with T1/T2 stage (organ-confined disease) and Gleason score <7. For each of these patients, we calculated annual price-weighted counts of advanced imaging studies for which prostate cancer was the primary diagnosis code (Appendix Table 4 lists CPT codes included in this measure).

Statistical Analysis

We used multilevel models to estimate mean differences in imaging use between Medicare and VA cohorts within HRRs, variation in use across HRRs for each cohort, and regional correlations in use between cohorts. Specifically, we fitted a linear regression model predicting annual price-weighted counts of imaging studies as a function of cohort (VA versus Medicare), patient and area-level sociodemographic characteristics listed in Table 1, indicators for the year of service (2003–2005), size of the Medicare population in each HRR, (31) indicators for each permutation of cancer type, stage, and grade, an indicator of a prior cancer history, and random effects for each cohort estimating average use of imaging per patient in each HRR. We specified an unstructured covariance matrix for the two cohort-specific random effects to estimate an HRR-level variance for each cohort and an HRR-level correlation in mean use between cohorts (Appendix). We also fitted separate models for each type of cancer.

In a sensitivity analysis, we included Charlson comorbidity scores and an indicator of death during the year as model covariates to gauge the potential contribution of unmeasured clinical characteristics to differences between Medicare and VA patients in mean use and variation in use. We omitted Charlson scores from our principal models because of financial incentives to code more inpatient diagnoses that are specific to Medicare and known geographic variation in Medicare coding practices.(38) To facilitate interpretation of model estimates, for each cohort we also estimated mean adjusted use of cancer-related imaging for quintiles of HRRs, using HRR-level adjusted mean use from the multilevel model to rank HRRs separately for each cohort. Finally, we decomposed mean differences between cohorts by imaging modality.

RESULTS

The VA cohort included 6835 men with lung, colorectal, or prostate cancer and 17,232 person-years from 2003–2005 across 40 HRRs (mean, 431 person-years/HRR; interquartile range, 310–554). The Medicare cohort included 34,475 men with these cancers and 87,977 person-years from 2003–2005 across the same 40 HRRs (mean, 2199 person-years/HRR; interquartile range, 279–3625). In the year of diagnosis, 33.7% of VA patients receiving 1 imaging study received 1 study reimbursed by Medicare, whereas only 19.5% of VA patients receiving 1 *cancer-related* imaging study received 1 *cancer-related* study reimbursed by Medicare (i.e., 80.5% received all studies in the VA).

Table 1 presents within-HRR comparisons of sociodemographic and clinical characteristics between the Medicare and VA cohorts. VA patients were younger, were less likely to be white, married, or have a prior cancer history, had lower Charlson comorbidity scores but a similar annual mortality rate, and lived in areas with lower levels of income, education, and employment in professional occupations. VA patients were more likely to be diagnosed with extensive small cell lung cancer but less likely to have late stage (IIIB/IV) non-small cell lung cancer, late stage colorectal cancer, or metastatic prostate cancer.

Adjusted annual use of cancer-related imaging was lower in the VA cohort than in the Medicare cohort (mean price-weighted utilization count, \$197 vs. \$379/patient; difference, –

\$182; 95%CI, -\$208--\$156; $P<0.001$). Lower use of computed tomography, positron emission tomography, and nuclear studies in the VA cohort accounted for 90% of this difference (Figure 1 and Appendix Table 5). Lower use of magnetic resonance imaging and ultrasound contributed as well, while use of x-rays was higher in the VA cohort than in the Medicare cohort. Cancer-related imaging use was lower in the VA cohort for each cancer type (Table 2).

Variation in adjusted per-patient use of cancer-related imaging across HRRs in the VA cohort (standard deviation (SD) in HRR mean price-weighted utilization count,\$78; 95%CI, \$60-\$101) was similar in magnitude to variation in the Medicare cohort (SD, \$60; 95%CI, \$45-\$79), as shown in Figure 2. In the Medicare cohort, adjusted annual use of cancer-related imaging was \$141/patient (or 47%) higher in HRRs in the highest quintile of use than in HRRs in the lowest quintile (Appendix Figure). In the VA cohort, adjusted annual use of cancer-related imaging was \$237/patient (or 240%) higher in HRRs in the highest quintile of use than in HRRs in the lowest quintile. Geographic variation was moderately correlated between the two cohorts ($r=0.53$; 95%CI, 0.17–0.76; $P<0.001$), but correlations were imprecise and not consistently positive and significant across cancer types (Table 2).

Adjusted annual use of advanced imaging for low-risk prostate cancer also was significantly lower in the VA than in the Medicare cohort (\$41 vs. \$117/patient; difference, -\$76; 95%CI, -\$89--\$62; $P<0.001$) and also varied across HRRs to similar extents in the VA (SD,\$29; 95%CI,\$21-\$40) and Medicare cohorts (SD,\$39; 95%CI,\$30-\$51).

In sensitivity analyses, the difference in adjusted use of cancer-related imaging between cohorts was slightly wider after adjustment for Charlson comorbidity scores (-\$185/patient) or death (-\$183/patient), and estimates of geographic variation did not substantively differ from our main results. Adjusted total use of imaging (not just cancer-related imaging) was also significantly lower in the VA cohort than in the Medicare cohort and exhibited similarly wide geographic variation in both cohorts (Appendix).

DISCUSSION

In this study of older men with lung, colorectal, or prostate cancer, use of cancer-related imaging was nearly 50% lower for a cohort of patients in the VA health care system than for a cohort of Medicare beneficiaries in the same geographic areas. Imaging modalities typically used for cancer staging and surveillance accounted for most of this difference. A measure of imaging overuse for patients with prostate cancer at low risk of metastasis detected 65% lower use in the VA cohort than in the Medicare cohort. In concert with previous research suggesting equal or better quality of cancer care in the VA than in traditional fee-for-service Medicare,(14,15) these findings suggest more efficient use of cancer-related imaging in the VA health care system.

Lower levels of cancer-related imaging in the VA cohort, however, were not associated with less geographic variation. This finding is consistent with prior studies demonstrating similarly wide geographic variation in utilization despite differences in health care financing and/or organization(39–43) and contributes to evidence that practices vary substantially

within the VA system despite widespread use of clinical practice guidelines and a resource allocation system that bases area-level budgets on case mix and local input costs but not care intensity.(29,44–51) By comparing settings with distinct rather than shared payment and delivery systems, our study offers a sharper contrast than assessments of the influence of managed care on geographic variations in care for Medicare or commercially insured populations.(41,42) In addition, using linked administrative and cancer registry data, we were able to assess actual use in the VA system rather than allocated costs,(39) identify and include Medicare-reimbursed care for VA patients, adjust for clinically relevant information (i.e., tumor characteristics), and confirm that between-system differences in use included more specific differences in directly measured overuse. Thus, our study provides a robust test of whether a system achieving more efficient use of a costly set of services necessarily exhibits less geographic variation in use of those services.

In general, there are many reasons why distinguishing features of the VA system—such as structural integration of the delivery system, salaried physicians, and use of global budgets to control spending—might be associated with lower average use of health care services but not with less geographic variation relative to Medicare. Because wasteful practices may be prevalent everywhere, even in areas with the most efficient providers,(7,52) uniformly applied systems to limit overuse may not necessarily affect high-use areas the most. Differences in provider productivity resulting from differences in training and expertise (e.g., some providers ordering more services than others to achieve the same outcome) and variation in practice norms and physician beliefs may contribute equally to variation in the VA and Medicare systems.(5,52–55) Physician responses to salary incentives and performance bonuses may be as heterogeneous as their responses to fee-for-service incentives. Similarly, VA medical centers operating under budgets may prioritize services differently, leading to heterogeneity in capacity to provide a given type of service. Finally, variation in unmeasured patient characteristics could contribute to variation in risk-adjusted utilization in both systems.(56)

The correlation in cancer-related imaging between the VA and Medicare cohorts was significantly positive overall but moderate in strength and was negative or weakly positive and not statistically significant for two of the three cancers we examined. These findings are consistent with prior research demonstrating weak geographic correlations in other cancer-related services between the same cohorts of patients(29) and suggest that common area-level factors did not explain most of the geographic variation in each system. Due to data limitations, we could not identify specific factors explaining geographic variation in either cohort or correlations between cohorts, and we could not determine whether higher use in an area was due to greater use of inappropriate or appropriate imaging, except in the case of one direct measure of overuse.

Our results have important implications for assessing health system performance. In concert with prior research,(14,15,57) they suggest that achievement of lower average spending and better average quality for a clinical condition in a system may not be associated with less geographic variation in care intensity for that condition. Because the extent of variation may not signal the level of system efficiency, research documenting geographic variation in risk-adjusted use of medical services may not be useful for reliably characterizing the amount of

wasteful care in a system. Within-system variation in performance on direct measures of overuse and quality at a facility or provider group level, on the other hand, may be useful for targeting improvement efforts, regardless of system-wide average levels of quality and utilization.(7,45–47) Likewise, our findings do not diminish the potential contributions of research exploring the causes of geographic variations to the understanding of physician behavior.(58)

Our study had several limitations. Our analysis was limited to imaging for cancer patients in 2003–2005, but in the context of prior research on quality of cancer care for Medicare and VA patients,(14,15) this period and category of services provided an instructive case for testing whether geographic variation necessarily reflects the extent of overuse.

Unmeasured differences in clinical characteristics between Medicare and VA patients could have contributed to differences in imaging use, but our estimates were largely unaffected by additional adjustment for observed comorbidities and death. Moreover, omitted clinical information would not affect our interpretation of the substantial difference in use of advanced imaging for low-grade prostate cancer as evidence of greater overuse in Medicare. We were also unable to adjust for differences in VA and Medicare benefits or other unmeasured factors affecting patient demand, such as preferences for aggressive care. Because we could not observe care in the VA system for eligible veterans in the Medicare cohort, we likely underestimated differences in imaging use between cohorts. Use of Medicare-reimbursed care by VA patients may have contributed to similar geographic variation and a positive correlation between cohorts, but our analysis limited exposure of the VA cohort to the Medicare program by focusing on cancer-related imaging that was largely confined to the VA system for VA patients, like other aspects of cancer care.(27) Moreover, sensitivity analyses suggested that dual use in both systems did not likely explain the similar extent of geographic variation within each system. Finally, less frequent coding of cancer diagnoses for cancer-related imaging studies in the VA could have contributed to between-system differences and within-system variation, but analyses of total use of imaging supported similar conclusions.

In summary, recent evidence suggests that policies directly addressing geographic variations in service use may not achieve greater efficiency in health care.(3,5) Our study further suggests that more efficient service use may not be associated with less geographic variation.

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APPENDIX. ADDITIONAL METHODS AND RESULTS

Measuring Use of Imaging Studies with Medicare Claims and VA Utilization Data

Using the Berenson-Eggers Type of Service classification of Current Procedural Terminology (CPT) codes to identify all imaging services,(34) we selected 241 CPT codes that accounted for 95.9% of all imaging services in 2005 Medicare claims for the Medicare cohort and 95.4% of imaging services in 2005 VA utilization data for the VA cohort. After excluding ancillary services that may be billed separately (e.g., contrast administration), 197 primary codes for imaging studies remained (Appendix Table 3), accounting for 90.4% and 92.1% of instances of imaging codes in Medicare claims and VA utilization data, respectively.

From Medicare claims, we calculated a standardized price for each CPT code equal to the national mean payment for each imaging study, covering both professional and technical components. For each patient in each cohort, we then summed imaging studies across claims or utilization files, weighting each study by its standardized price and removing duplicate references to the same study (i.e., same patient, CPT code, and date of service). Thus, although expressed in dollars, these price-weighted counts measure utilization and are unaffected by geographic variation in prices. Allowing a fuzzy match on date of service (+/- 2 days) to remove duplicate studies did not significantly affect counts of imaging studies.

For the Medicare cohort, we summed imaging studies in Carrier and Outpatient claims files covering both inpatient and outpatient imaging. For the VA cohort, we summed imaging studies in Decision Support System National Data Extract files covering inpatient and outpatient care from VA providers, Fee Basis files covering contracted care from non-VA

providers, and Medicare Carrier and Outpatient claims files covering Medicare-reimbursed care from non-VA providers.(35–37) Therefore, utilization counts captured imaging outside of the VA system for Medicare beneficiaries in the VA cohort but not imaging in the VA system for eligible veterans in the Medicare cohort.

Addressing Potential Differences in Coding Practices between VA and Medicare

To address potential differences in coding of imaging studies between VA and non-VA providers, we collapsed the 197 imaging CPT codes into 96 groups of similar studies (e.g., magnetic resonance imaging (MRI) of the brain with contrast was grouped with MRI of the brain with and without contrast) and applied the highest standardized price in each group to all studies in the group (see Appendix Table 3 for groupings and group prices). Results were not altered substantially by this modification, which we included in our main analysis.

To address potential differences in coding of cancer diagnoses for cancer-related imaging studies, we calculated the proportion of imaging studies in Medicare claims vs. VA utilization files that had a primary diagnosis of lung, colorectal, or prostate cancer as opposed to any other diagnosis. Among imaging studies for the study population, this proportion was 5 percentage points higher in VA utilization data than in Medicare claims, suggesting that the between-system difference in use of cancer-related imaging was not likely explained by less frequent coding of cancer diagnoses for imaging studies in the VA. That the proportion of studies with a cancer diagnosis was higher in the VA is also consistent with cancer care being more concentrated within the VA than care for other conditions. Moreover, in a supplemental analysis, we analyzed total use of imaging for the two cohorts (regardless of diagnosis) and found a pattern of results that was similar to those we report for cancer-related imaging (a significant between-system difference in imaging use but a similar extent of geographic variation in both systems). As demonstrated in a subsequent section of this appendix, however, analyses of total use of imaging—while unaffected by differences in diagnostic coding between the VA and Medicare—likely underestimated between-cohort differences in imaging because of greater dual use in both systems of imaging that was not directly related to cancer.

Statistical Methods

To estimate mean differences in use of cancer-related imaging between Medicare and VA cohorts within HRRs, variation in use across HRRs for each cohort, and regional correlations in use between cohorts, we fitted the following linear mixed model:

$$Y_{itk} = \beta_{00}I^M_i + \beta_{01}I^{VA}_i + \beta X_{itk} + u_{00k}I^M_i + u_{01k}I^{VA}_i + e_{itk}I^{VA}_i + e_{itk}I^M_i$$

where Y_{itk} is the price-weighted count of cancer-related imaging studies for patient i in year t and HRR k , I^M is an indicator of the Medicare cohort, I^{VA} is an indicator of the VA cohort, X is a vector of covariates described in the Statistical Analysis section of the Methods, and u_{00k} and u_{01k} are the HRR-specific random effects for the Medicare and VA cohorts,

respectively. Thus, for each cohort ($I^M=1$ or $I^{VA}=1$), the model estimates adjusted mean use overall and in each HRR. We assumed the random effects follow a bivariate normal distribution with mean equal to zero, and we specified an unstructured covariance matrix for the random effects to estimate an HRR-level variance for the Medicare cohort (σ_{u00}^2) and VA cohort (σ_{u01}^2) and an HRR-level correlation in mean use between cohorts. We assumed the residual patient variation (e_{itk}) followed a normal distribution and allowed a separate variance term for each cohort.

Because of the complexity of the model and the small number of repeated observations (11% of the study population with a single observation, 23% with 2 and 66% with 3), we assumed repeated observations within an individual were independent. In a sensitivity analysis, we specified a correlation matrix for the residuals that was autoregressive with respect to an individual's sequence of observations (year relative to diagnosis), and estimates from this sensitivity analysis were very close to those that we report, with no change in interpretation. We used the models assuming independence in our primary approach (and for the many sensitivity analyses we conducted) because they are far more computationally efficient. In another sensitivity analysis, we restricted the cohort to the year of diagnosis (1 observation per patient for all patients and thus no repeated observations), and our conclusions were unaltered.

In addition to linear mixed models, we fitted generalized linear mixed models with a log link and proportional to mean variance function and obtained substantively similar results. The HRR-level correlation in use of cancer-related imaging between the VA and Medicare cohorts was somewhat lower when estimated using this alternative specification (0.37 vs. 0.53) but well within the wide confidence interval of the estimate from the linear model. Finally, to check the robustness of estimates to the exclusion of HRRs with small numbers of cancer patients in either cohort, we increased the minimum threshold for inclusion to 100 person-years per HRR in each cohort (excluding 7 HRRs); results were not appreciably affected by this exclusion.

Results from Analysis of Total Use of Imaging Studies for Patients with Cancer

We repeated analyses for total use of imaging studies (not just cancer-related imaging). Like cancer-related imaging, adjusted annual total use of imaging was lower in the VA cohort than in the Medicare cohort (\$1264 vs. \$1368/patient; difference, $-\$104$; 95% CI, $-\$180$ – $\$27$; $P=0.008$) and exhibited similar variation across HRRs in the VA cohort (SD, \$215; 95% CI, \$168–\$276) and Medicare cohort (SD, \$200; 95% CI, \$156 to \$255). In the Medicare cohort, adjusted annual use of imaging overall was \$540/patient (or 47%) higher in HRRs in the highest quintile of use than HRRs in the lowest quintile. In the VA cohort, adjusted annual use of imaging overall was \$611/patient (or 63%) higher in HRRs in the highest quintile of use than HRRs in the lowest quintile. As described in the next section of the Appendix, differences in total use of imaging studies between cohorts were not bigger than differences in cancer-related imaging use likely because of the much greater extent of dual use in both systems of imaging studies without cancer-related diagnoses.

Sensitivity Analyses Assessing the Impact of Dual Use

The utilization data we analyzed captured imaging outside of the VA system for Medicare beneficiaries in the VA cohort but not imaging in the VA system for eligible veterans in the Medicare cohort (we did not have identifiers to link the Medicare cohort with VA data). We conducted two sensitivity analyses to assess the influence of dual use of imaging in both Medicare and VA systems by patients in either cohort on our results. First, to gauge the impact of omitting any VA-provided care for the Medicare cohort on our results, we conducted analyses of cancer-related imaging from 2001–2005 for cohorts of Medicare and VA patients diagnosed in earlier years (2001–2002), for whom we had data on eligibility for VA health benefits (we lacked these data for those diagnosed in 2003–2004). After excluding patients from the Medicare cohort who were eligible for VA health benefits, the difference in adjusted annual use of *cancer-related* imaging between these earlier diagnosed cohorts of Medicare and VA patients grew wider by \$16 (i.e., use in the VA cohort an additional \$16 less than in the Medicare cohort), geographic variation in use remained similar between the cohorts, and the regional correlation in use between cohorts declined by 0.11. After this exclusion, the difference in adjusted annual *total* use of imaging grew wider by \$73 (i.e., use in the VA cohort an additional \$73 less), geographic variation in use remained similar between the cohorts, and the regional correlation in use between cohorts declined by 0.13.

Second, from our main analyses of imaging from 2003–2005 for patients diagnosed in 2003–2004, we alternately excluded two groups of patients from the VA cohort: A) those who received at least 1 cancer-related imaging study reimbursed by Medicare (1124 person-years), and B) those who received any imaging study reimbursed by Medicare (5434 person-years). After exclusion A, the difference in adjusted annual use of cancer-related imaging between the VA and Medicare cohorts was –\$230/patient (vs. –\$182/patient in our main analysis without this exclusion) and the difference in adjusted annual total use of imaging was –\$176/patient (vs. –\$103 without this exclusion). After exclusion B, the difference in adjusted annual use of cancer-related imaging between the VA and Medicare cohorts was similar to the difference after exclusion A (–\$229/patient), but the difference in total adjusted annual use of imaging between cohorts was much wider (–\$357/patient). After these exclusions, geographic variation in imaging use remained similar between cohorts; model estimates of variation in the VA cohort remained higher than but were closer to estimates of variation in the Medicare cohort. Correlation coefficients were 0.09 to 0.13 lower after these exclusions.

Thus, these findings suggest that we likely underestimated differences in imaging use—particularly differences in total use of imaging—between the Medicare and VA systems because of dual use in both systems by some patients. Excluding VA patients with Medicare-reimbursed imaging (exclusion B) may have selectively removed patients from the VA cohort with unmeasured clinical characteristics that warranted more imaging. This possibility is unlikely, however, because the addition of the Charlson Comorbidity Index and an indicator of death during the year as model covariates did not significantly change differences in total use of imaging between the VA and Medicare cohorts after exclusion B (as we found in our main analyses). We therefore conclude that, in the absence of dual use,

differences in total use of imaging between the VA and Medicare cohorts would have been much greater than we report in the preceding section of the Appendix and much greater than differences in use of cancer-related imaging. For example, combining the results of our sensitivity analyses and extrapolating from the results for patients diagnosed in earlier years, use of total imaging would have been \$430/patient lower in the VA cohort ($-\$357 + -\73) and use of cancer-related imaging would have been \$245/patient lower ($-\$229 + -\16) in the absence of dual use.

By extension, less frequent coding of cancer diagnoses for cancer-related imaging studies in the VA did not likely explain our finding of substantial between-system differences in cancer-related imaging. If the difference in cancer-related imaging between cohorts was entirely due to differences in coding, for example, then it should have grown more than the difference in total imaging use when we excluded VA patients with imaging use reimbursed by Medicare, because capture of cancer-related imaging (but not total imaging) would have been more complete for dual users of both systems than for patients with imaging in the VA only. We found the opposite, however, with the difference in total imaging use growing much more with this exclusion (by $-\$253$ for total imaging use vs. $-\$47$ for cancer-related imaging use—more than a 5-fold difference). In addition, if the between-system difference in cancer-related imaging use was due to systematically lower rates of cancer diagnosis coding for cancer-related imaging studies in the VA, we would expect consistently lower use of cancer-related imaging across all modalities. Use of x-ray studies with cancer diagnosis codes, however, was substantially higher in the VA cohort than in the Medicare cohort (Appendix Table 5). Thus, our results were not likely driven by differences in coding practices between Medicare and the VA, and the smaller between-system differences in total imaging use (vs. the difference in cancer-related imaging use) is more consistent with greater dual use of imaging that was not directly related to cancer, or conversely, with greater concentration of cancer-related imaging within the VA for patients in the VA cohort.

These sensitivity analyses also suggest that dual use did not likely explain the observed similarity between Medicare and VA cohorts in the extent of geographic variation in imaging use but did contribute to correlations that were more positive than would be observed in the absence of dual use.

Analyses of Unweighted Counts of Imaging Studies by Modality

In addition to our main analyses of price-weighted counts of utilization, we analyzed unweighted counts of cancer-related imaging studies within each imaging modality. Appendix Table 5 summarizes the results of these analyses. As expected, between-system differences in use of higher cost modalities became relatively smaller and differences in lower cost modalities became relatively larger when analyzing unweighted rather than price-weighted counts of imaging studies. Differences in unweighted use of modalities typically used for cancer staging and surveillance (computed tomography, positron emission tomography, and nuclear studies) nevertheless remained significant and, combined, explained much of the overall difference in cancer-related imaging use. As in our main analysis of price-weighted counts, unweighted counts of cancer-related x-ray studies were significantly higher in the VA cohort than in the Medicare cohort, suggesting possible

substitution of higher cost modalities for x-ray studies in the Medicare cohort. Geographic variation in unweighted counts was similar in both cohorts for all modalities (though variation in use of PET studies tended to be greater in the VA and variation in use of ultrasound studies tended to be greater in Medicare), and correlations varied considerably across modalities. We analyzed price-weighted counts of imaging studies in our main analyses because they better reflect between-system differences and within-system variation in resource use and can be combined across studies and modalities to summarize the net effects of differences in use of a given study over no imaging and differences in use of a more costly study over a less costly study. Because different modalities may substitute for one another, we caution against normative interpretations from comparisons across modalities of the extent of geographic variation within the Medicare or VA cohort. For example, if use of computed tomography studies substitutes for use of ultrasound studies to some extent, geographic variation in the use of computed tomography studies would lead to geographic variation in the use of ultrasound studies.

Finally, in a sensitivity analysis, we also calculated for each modality the mean price of all studies performed within that modality and applied the modality-specific mean price to all studies in a given modality when constructing summary price-weighted utilization counts across modalities. This adjustment, which held prices constant among studies within modality while allowing price differences between modalities to reflect differences in cost, did not alter our conclusions.

Appendix Figure. Geographic Variation in Cancer-related Imaging Use for Medicare vs. VA Cohort

For each cohort, adjusted mean use of cancer-related imaging is displayed by quintile of hospital referral regions (HRRs) in the cohort's HRR-level ranking of mean adjusted use (HRRs were ranked separately for each cohort). In the Medicare cohort, adjusted annual use of cancer-related imaging was \$141/patient (or 47%) higher in HRRs in the highest quintile of use than in HRRs in the lowest quintile. In the VA cohort, adjusted annual use of cancer-related imaging was \$237/patient (or 240%) higher in HRRs in the highest quintile of use than in HRRs in the lowest quintile. Error bars indicate 95% confidence intervals.

Appendix Table 1

Hospital Referral Regions Included in the Analysis

HRR Name	State
Phoenix	AZ
Fresno	CA
Los Angeles	CA
Sacramento	CA
San Bernardino	CA
San Diego	CA
San Francisco	CA
San Mateo County	CA
New Haven	CT
Wilmington	DE
Atlanta	GA
Augusta	GA
Macon	GA
Des Moines	IA
Iowa City	IA

HRR Name	State
Lexington	KY
Louisville	KY
Paducah	KY
Alexandria	LA
New Orleans	LA
Shreveport	LA
Ann Arbor	MI
Detroit	MI
Minneapolis	MN
Jackson	MS
Omaha	NE
Las Vegas	NV
Reno	NV
Newark	NJ
Albuquerque	NM
Philadelphia	PA
Providence	RI
Sioux Falls	SD
Memphis	TN
Nashville	TN
Amarillo	TX
Lubbock	TX
Salt Lake City	UT
Seattle	WA
Huntington	WV

Appendix Table 2

Diagnosis Codes by Cancer Type

Cancer type	ICD-9 code	ICD-9 code definition
Lung	162	Malignant neoplasm of trachea, bronchus, and lung
	162.0	Trachea
	162.2	Main bronchus
	162.3	Upper lobe, bronchus or lung
	162.4	Middle lobe, bronchus or lung
	162.5	Lower lobe, bronchus or lung
	162.8	Other parts of bronchus or lung
	162.9	Bronchus and lung, unspecified
Prostate	185	Malignant neoplasm of prostate
Colorectal	153	Malignant neoplasm colon
	154	Malignant neoplasm of rectum, rectosigmoid junction, and anus

Cancer type	ICD-9 code	ICD-9 code definition
	154.0	Malignant neoplasm of rectosigmoid junction
	154.1	Malignant neoplasm of rectum
	154.2	Malignant neoplasm of anal canal
	154.8	Malignant neoplasm of other sites of rectum, rectosigmoid junction, and anus

Appendix Table 3

List of Imaging Studies Examined with Associated Current Procedural Terminology (CPT) Codes and Standardized Payments*

CPT	Imaging Study	CPT-specific Standardized Payment (weight)	CPT Group-specific Standardized Payment (weight)
Computerized Tomography (CT)			
70450	CT HEAD/BRAIN WITHOUT CONTRAST	\$207.35	\$313.68
70460	CT HEAD/BRAIN WITH CONTRAST	\$245.45	\$313.68
70470	CT HEAD WITH & WITHOUT CONTRAST	\$313.68	\$313.68
70480	CT ORBIT WITHOUT CONTRAST	\$228.76	\$238.07
70486	CT MAXILLOFACIAL WITHOUT CONTRAST	\$238.07	\$238.07
70490	CT NECK SOFT WITHOUT CONTRAST	\$245.36	\$381.73
70491	CT NECK SOFT WITH CONTRAST	\$313.38	\$381.73
70492	CT NECK SOFT WITH & WITHOUT CONTRAST	\$381.73	\$381.73
70496	CTA HEAD WITH & WITHOUT CONTRAST	\$413.70	\$414.05
70498	CTA NECK WITH & WITHOUT CONTRAST	\$414.05	\$414.05
71250	CT THORAX WITHOUT CONTRAST	\$248.77	\$364.76
71260	CT THORAX WITH CONTRAST	\$296.55	\$364.76
71270	CT, THORAX WITH & WITHOUT CONTRAST	\$364.76	\$364.76
71275	CTA CHEST WITH & WITHOUT CONTRAST	\$397.92	\$397.92
72125	CT CERVICAL WITHOUT CONTRAST	\$236.99	\$236.99
72128	CT THORACIC WITHOUT CONTRAST	\$225.11	\$225.11
72131	CT LUMBAR SPINE WITHOUT CONTRAST	\$237.59	\$307.41
72132	CT LUMBAR SPINE WITH CONTRAST	\$307.41	\$307.41
72191	CTA PELVIS WITH & WITHOUT CONTRAST	\$344.76	\$344.76
72192	CT PELVIS WITHOUT CONTRAST	\$236.93	\$293.42
72193	CT PELVIS WITH CONTRAST	\$231.41	\$293.42
72194	CT PELVIS WITH & WITHOUT CONTRAST	\$293.42	\$293.42
73200	CT UPPER EXTREMITY WITHOUT CONTRAST	\$231.24	\$231.24
73700	CT, LOWER EXTRM WITHOUT CONTRAST	\$231.90	\$298.09
73701	CT LOWER EXTREMITY WITH CONTRAST	\$298.09	\$298.09
73706	CTA LOWER EXTREMITY WITH & WITHOUT CONTRAST	\$412.79	\$412.79
74150	CT ABDOMEN WITHOUT CONTRAST	\$207.16	\$427.32

CPT	Imaging Study	CPT-specific Standardized Payment (weight)	CPT Group- specific Standardized Payment (weight)
74160	CT ABDOMEN WITH CONTRAST	\$345.07	\$427.32
74170	CT ABDOMEN WITH & WITHOUT CONTRAST	\$393.00	\$427.32
74175	CTA ABDOMEN WITH & WITHOUT CONTRAST	\$427.32	\$427.32
75635	CT ANGIO ABDOMINAL ARTERIAL	\$439.05	\$439.05
76380	CT LIMITED/LOCALIZED FOLLOW UP STUDY	\$134.75	\$134.75
77078	[†] CT BONE DENSITY STUDY	\$57.64	\$57.64
Positron Emission Tomography (PET)			
78608	PET BRAIN SINGLE SLICE	\$1,056.01	\$1,056.01
78811	TUMOR IMAGING (PET), LIMITED	\$1,109.56	\$1,109.56
78812	TUMOR IMAGE (PET)/SKULL BASE TO MID-THIGH	\$999.19	\$999.19
78813	Pet imaging for breast cancer, full and partial-ring pet scanners only, evaluation of response to treatment, performed during course of treatment.	\$948.76	\$948.76
78814	TUMOR IMAGE PET/CT, LIMITED	\$935.20	\$935.20
78815	TUMOR IMAGE PET/CT SKULL BASE TO MID-THIGH	\$1,055.94	\$1,055.94
78816	TUMOR IMAGE PET/CT FULL BODY	\$987.66	\$987.66
Magnetic Resonance Imaging (MRI)			
70540	MRI FACE & NECK	\$378.89	\$613.20
70543	MRI ORBIT, FACE, NECK WITHOUT CONTRAST	\$613.20	\$613.20
70544	MRA HEAD WITHOUT CONTRAST	\$348.28	\$574.74
70546	MRA HEAD WITH & WITHOUT CONTRAST	\$541.68	\$574.74
70547	MRA NECK WITHOUT CONTRAST	\$373.84	\$574.74
70548	MRA NECK WITH CONTRAST	\$410.16	\$574.74
70549	MRA NECK WITH & WITHOUT CONTRAST	\$574.74	\$574.74
70551	MRI BRAIN WITHOUT CONTRAST	\$412.99	\$618.43
70552	MRI BRAIN WITH CONTRAST	\$475.14	\$618.43
70553	MRI, BRAIN WITH & WITHOUT CONTRAST	\$618.43	\$618.43
71550	MRI CHEST MEDIASTINUM	\$389.27	\$580.05
71552	MRI CHEST WITH & WITHOUT CONTRAST	\$580.05	\$580.05
72141	MRI NECK SPINE WITHOUT CONTRAST	\$400.39	\$613.15
72146	MRI SPINAL THORAX WITHOUT CONTRAST	\$400.53	\$450.04
72147	MRI SPINAL THORAX WITH & WITHOUT CONTRAST	\$450.04	\$450.04
72148	MRI LUMBAR SPINE WITHOUT CONTRAST	\$403.54	\$608.31
72149	MRI LUMBAR SPINE WITH CONTRAST	\$480.90	\$608.31
72156	MRI NECK, SPINE WITH & WITHOUT CONTRAST	\$613.15	\$613.15
72157	MRI, THORAX SPINE WITH & WITHOUT CONTRAST	\$580.03	\$580.03
72158	MRI LUMBAR SPINE WITH & WITHOUT CONTRAST	\$608.31	\$608.31
72195	MRI PELVIS WITHOUT CONTRAST	\$405.11	\$649.47
72196	MRI PELVIS ANGIO WITH OR WITHOUT	\$513.32	\$513.32

CPT	Imaging Study	CPT-specific Standardized Payment (weight)	CPT Group- specific Standardized Payment (weight)
72197	MRI PELVIS WITH & WITHOUT CONTRAST	\$649.47	\$649.47
72198	MRI PELVIS ANGIO WITH OR WITHOUT	\$464.92	\$513.32
73218	MRI UPPER EXTREMITY OTHER THAN JOINT	\$388.61	\$575.39
73220	MRI, UPPER EXTREMITY WITHOUT JOINT	\$509.16	\$575.39
73221	MRI UPPER JOINT WITH OR WITHOUT CONTRAST	\$388.51	\$575.39
73222	MRI ANY JOINT UP EXTREMITY WITH CONTRAST	\$448.12	\$575.39
73223	MRI UPPER EXTREMITY WITH & WITHOUT CONTRAST	\$575.39	\$575.39
73718	MRI LOW EXTREMITY, NOT JOINT WITHOUT CONTRAST	\$392.18	\$607.21
73720	MRI LOWER XTRMTY JOINT	\$607.21	\$607.21
73721	MRI LOWER EXTREMITY JOINT	\$390.10	\$607.21
73723	MRI, JOINT LOWER EXTREMITY WITHOUT & WITH CONTRAST	\$554.06	\$607.21
73725	MRI ANGIO WITH & WITHOUT CONTRAST	\$419.46	\$419.46
74181	MRI ABDOMEN WITH & WITHOUT CONTRAST	\$414.58	\$657.00
74183	MRI ABDOMEN WITH & WITHOUT CONTRAST	\$657.00	\$657.00
74185	MRI ABDOMEN WITH OR WITHOUT CONTRAST	\$428.36	\$657.00
77058	MRI BREAST	\$774.54	\$862.06
77059	MRI BOTH BREASTS	\$862.06	\$862.06
Nuclear			
78223	[†] HEPATOBILIARY-HIDA SCAN	\$274.61	\$274.61
78278	[†] ACUTE GI BLOOD LOSS IMAGING	\$228.89	\$228.89
78306	BONE IMAGING WHOLE BODY	\$233.04	\$276.25
78315	BONE IMAGING, THREE PHASE	\$276.25	\$276.25
78320	BONE IMAGING, TOMOGRAPHIC	\$239.30	\$276.25
78459	[†] MYOCARDIAL IMAGING, PET, METABOLIC EVALUATION	\$1,211.11	\$1,211.11
78464	[†] MYOCARDIAL PERFUSION TOMOGRAPHIC	\$235.24	\$1,211.11
78465	[†] MYOCARDIAL PERFUSION (SPECT)	\$463.58	\$1,211.11
78472	[†] Cardiac blood pool imaging, gated equilibrium; planar, single study at rest or stress (exercise and/or pharmacologic), wall motion study plus ejection fraction, with or without additional quantitative processing	\$232.79	\$1,211.11
78473	[†] 78472 + multiple studies, wall motion study plus ejection fraction, at rest and stress (exercise and/or pharmacologic), with or without additional quantification	\$269.78	\$1,211.11
78478	[†] MYOCARDIAL PERFUSION STUDY	\$57.15	\$1,211.11
78480	[†] MYOCARD PERFUSION STUDY WITH EXERCISE	\$47.72	\$1,211.11
78481	[†] Cardiac blood pool imaging, (planar), first pass technique; single study, at rest or with stress (exercise and/or pharmacologic), wall motion study plus ejection fraction, with or without quantification	\$186.10	\$1,211.11
78483	[†] 78481 + multiple studies, at rest and with stress (exercise and/or pharmacologic), wall motion study plus ejection	\$176.57	\$1,211.11

CPT	Imaging Study	CPT-specific Standardized Payment (weight)	CPT Group- specific Standardized Payment (weight)
fraction, with or without quantification			
78492	[†] MYOCARD PET MULTIPLE	\$1,073.25	\$1,211.11
78494	[†] Cardiac blood pool imaging, gated equilibrium, SPECT, at rest, wall motion study plus ejection fraction, with or without quantitative processing	\$283.94	\$1,211.11
78580	PULMONARY PERFUSION, PARTICULATE ONLY	\$119.12	\$307.34
78585	LUNG AREOSOL & PERFUSION	\$295.64	\$307.34
78588	PULMONARY PERFUSION IMAGING	\$307.34	\$307.34
78596	QUANTITATIVE VQ SCAN DIFFERENTIAL	\$297.80	\$307.34
78707	KIDNEY IMAGING/VASCULAR FLOW	\$223.51	\$223.51
78802	TUMOR IMAGING WHOLE BODY	\$191.37	\$321.74
78803	TUMOR LOCALIZATION, TOMOGRAPHIC	\$321.74	\$321.74
Ultrasound			
76512	[†] ECHO EXAM OF EYE	\$86.39	\$86.39
76536	SONOGRAM HEAD & NECK	\$106.83	\$106.83
76604	SONOGRAM, CHEST	\$65.99	\$65.99
76645	SONOGRAM BREAST	\$87.17	\$87.17
76700	SONOGRAM, ABDOMEN	\$127.99	\$127.99
76705	SONOGRAM LIMITED ABDOMEN	\$95.20	\$127.99
76770	SONOGRAM RETROPERITONEUM	\$123.12	\$123.12
76775	SONOGRAM RENAL DOPPLER	\$105.90	\$105.90
76830	ECHOGRAPHY TRANSVAGINAL	\$115.07	\$116.39
76856	SONOGRAM, PELVIS	\$116.39	\$116.39
76857	SONOGRAM, PELVIS LIMITED	\$78.79	\$116.39
76870	SONOGRAM, SCROTUM	\$116.40	\$116.40
76872	ECHOGRAPHY TRANSRECTAL	\$125.25	\$148.74
76873	ECHO TRANSRECTAL; PROSTATE	\$148.74	\$148.74
76880	SONOGRAM, EXTREMITY	\$114.61	\$114.61
76942	[†] SONOGRAM, BIOPSY PANCREAS	\$164.26	\$164.26
76950	[†] RADIOTHERAPY SCAN B MODE	\$70.82	\$70.82
93307	[†] ECHO EXAM OF THE HEART CONTRAST	\$138.72	\$138.72
93308	[†] ECHO EXAM OF HEART FOLLOW UP	\$99.91	\$138.72
93312	[†] TRANSESOPHAGEAL ECHO	\$174.21	\$174.21
93320	[†] DOPPLER ECHO/PULSE WAVE	\$28.28	\$28.28
93325	[†] SONOGRAM, CAROTID	\$16.52	\$28.28
93880	[†] DUPLEX SCAN EXTRACRANIAL	\$171.92	\$171.92
93882	[†] DUPLEX SCAN EXTRACRANIAL	\$138.64	\$171.92
93925	DUPLEX SCAN LOWER EXTREMITY	\$165.75	\$165.75
93926	LOWER EXTREMITY STUDY	\$103.73	\$165.75
93970	DUPLEX SCAN EXTREMITY VEIN BILATERAL	\$171.27	\$171.27

CPT	Imaging Study	CPT-specific Standardized Payment (weight)	CPT Group- specific Standardized Payment (weight)
93971	DUPLEX SCAN EXTREMITY VEIN	\$108.10	\$171.27
93975	ECHO ARTERY INFLOW, VENOUS OUTFLOW	\$227.08	\$227.08
93976	PELVIS/SCROTUM/RETROPERITONEAL	\$173.70	\$173.70
93978	DUPLEX SCAN OF AORTA ETC.	\$171.81	\$171.81
93979	DUPLEX SCAN AORTA/IVC/GF	\$108.09	\$171.81
X-Ray			
G0204	Diagnostic mammography, producing direct digital image, bilateral, all views	\$146.01	\$146.01
G0202	Screening mammography, producing direct digital image, bilateral, all views	\$124.72	\$146.01
G0206	Diagnostic mammography, producing direct digital image, unilateral, all views	\$114.66	\$146.01
70220	SINUSES 3 OR MORE VIEWS	\$34.24	\$34.24
71010	CHEST X-RAY	\$21.38	\$31.73
71020	CHEST 2 VIEWS	\$29.36	\$31.73
71035	CHEST SPECIAL DECUBITUS, ETC	\$31.73	\$31.73
71100	RIBS UNILATERAL 2 VIEWS	\$30.07	\$34.44
71101	RIBS UNILATERAL 3 OR MORE VIEWS	\$34.44	\$34.44
72010	SPINE ENTIRE AP & LAT	\$46.88	\$46.88
72040	SPINE CERVICAL, 2 OR MORE VIEWS	\$28.95	\$59.58
72050	SPINE, CERVICAL 4 VIEWS	\$47.30	\$59.58
72052	SPINE CERVICAL 6 VIEWS	\$59.58	\$59.58
72070	SPINE THORACIC 2 VIEWS	\$29.12	\$35.65
72072	SPINE THORC AP & LAT & SWIM	\$35.65	\$35.65
72100	SPINE LUMBOSACRAL 2 VIEWS	\$33.25	\$64.77
72110	SPINE LUMBO 4 VIEWS	\$50.71	\$64.77
72114	SPINE LUMBOSACRAL 6 OR MORE VIEWS	\$64.77	\$64.77
72170	PELVIS 1 OR 2 VIEWS	\$23.31	\$23.31
73030	SHOULDER 2 OR MORE VIEWS	\$27.33	\$27.33
73060	HUMERUS 2 OR MORE VIEWS	\$25.85	\$25.85
73070	ELBOW 2 VIEWS	\$23.83	\$31.08
73080	ELBOW 3 OR MORE VIEWS	\$31.08	\$31.08
73100	WRIST 2 VIEWS	\$24.95	\$30.54
73110	WRIST 3 OR MORE VIEWS	\$30.54	\$30.54
73120	HAND 1 OR 2 VIEWS	\$24.79	\$28.44
73130	HAND 3 OR MORE VIEWS	\$28.44	\$28.44
73140	FINGER(S) 2 OR MORE VIEWS	\$25.12	\$25.12
73500	HIP 1 VIEW	\$22.32	\$36.44
73510	HIP 2 OR MORE VIEWS	\$32.17	\$36.44
73520	HIPS BILATERAL 4 OR MORE VIEWS	\$36.44	\$36.44

CPT	Imaging Study	CPT-specific Standardized Payment (weight)	CPT Group- specific Standardized Payment (weight)
73550	FEMUR 2 VIEWS	\$24.30	\$36.44
73560	KNEE 2 VIEWS	\$25.66	\$37.12
73562	KNEE 3 VIEWS	\$31.34	\$37.12
73564	KNEE 4 OR MORE VIEWS	\$37.12	\$37.12
73565	KNEE, STANDING, ANTEROPOSTERIOR	\$27.00	\$37.12
73590	TIBIA & FIBULA 2 VIEWS	\$24.02	\$24.02
73600	ANKLE 2 VIEWS	\$23.89	\$27.52
73610	ANKLE 3/MORE VIEWS	\$27.52	\$27.52
73620	FOOT 2 VIEWS	\$24.42	\$28.17
73630	FOOT 3 OR MORE VIEWS	\$28.17	\$28.17
74000	ABDOMEN 1 VIEW	\$23.29	\$43.65
74010	ABDOMEN 2 VIEWS	\$34.32	\$43.65
74020	ABDOMEN 3 OR MORE VIEWS	\$36.77	\$43.65
74022	ABDOMEN 3 OR MORE VIEWS & CHEST	\$43.65	\$43.65
74220	ESOPHAGUS, GASTROGRAFIN SMA	\$77.15	\$77.15
74230	ESOPHAGUS RAPID SEQUENCE	\$75.30	\$77.15
74245	UPPER GI + SMALL BOWEL	\$168.16	\$178.31
74246	UPPER GI AIR CONTRAST WITHOUT KUB	\$114.94	\$178.31
74247	UPPER GI AIR CONTRAST WITH KUB	\$122.20	\$178.31
74249	UPPER GI AIR WITH SMALL BOWEL	\$178.31	\$178.31
74250	SMALL BOWEL MULTI FILMS	\$95.57	\$178.31
74270	COLON BARIUM ENEMA	\$115.96	\$185.48
74280	COLON AIR CONTRAST	\$185.48	\$185.48
74400	UROGRAM INTRAVENOUS	\$101.39	\$123.43
74415	UROGRAM WITH NEPHROTOMOGRAM	\$123.43	\$123.43
74420	UROGRAM RETROGRADE	\$104.82	\$123.43
77052	COMPUTER-AIDED MAMMOGRAM (ADDITIONAL)	\$11.47	\$146.01
77055	MAMMOGRAM, UNILATERAL	\$79.31	\$146.01
77056	MAMMOGRAM BILATERAL	\$99.95	\$146.01
77057	MAMMOGRAM SCREENING	\$76.49	\$146.01
77075	BONE SURVEY COMPLETE (AXIAL AND APPENDICULAR SKELETON)	\$95.45	\$95.45
77080	[†] BONE DENSITY (DUAL ENERGY)	\$63.22	\$63.22

* CPT codes for imaging studies as of 2009, the year of Medicare claims that we used to develop standardized prices. For codes updated between the study period and 2009, we applied the standardized prices to predecessor codes appearing in 2003–2005 claims.

[†] In a sensitivity analysis, we excluded these 25 imaging studies that were not likely to be directly related to care for lung, colorectal, or prostate cancer. Adjusted mean use of cancer-related imaging in the VA and Medicare cohorts and the difference in cancer-related imaging use between cohorts were not significantly changed by these exclusions, confirming that these studies contributed minimally to the measure of cancer-related imaging (i.e., these studies were rarely ordered with a primary diagnosis code of lung, colorectal, or prostate cancer). We included these studies in analyses of total use of imaging because they may have been indirectly related to cancer (e.g., echocardiograms to assess for chemotherapy-related cardiomyopathy or preoperative studies before major cancer surgery) or may have reflected more aggressive care for cancer.

patients in general (e.g., myocardial perfusion scans to screen for coronary artery disease in patients with metastatic disease).

Appendix Table 4

Imaging Studies Included in Measure of Advanced Imaging for Prostate Cancer with Low Risk of Metastasis

CPT	Imaging Study
70450	CT HEAD/BRAIN WITHOUT CONTRAST
70460	CT HEAD/BRAIN WITH CONTRAST
70470	CT HEAD WITH & WITHOUT CONTRAST
70544	MRA HEAD WITHOUT CONTRAST
70546	MRA HEAD WITH & WITHOUT CONTRAST
70551	MRI BRAIN WITHOUT CONTRAST
70552	MRI BRAIN WITH CONTRAST
70553	MRI, BRAIN WITH & WITHOUT CONTRAST
71250	CT THORAX WITHOUT CONTRAST
71260	CT THORAX WITH CONTRAST
71270	CT, THORAX WITH & WITHOUT CONTRAST
71550	MRI CHEST MEDIASTINUM
71552	MRI CHEST WITH & WITHOUT CONTRAST
72125	CT CERVICAL WITHOUT CONTRAST
72128	CT THORACIC WITHOUT CONTRAST
72131	CT LUMBAR SPINE WITHOUT CONTRAST
72132	CT LUMBAR SPINE WITH CONTRAST
72141	MRI NECK SPINE WITHOUT CONTRAST
72146	MRI SPINAL THORAX WITHOUT CONTRAST
72147	MRI SPINAL THORAX WITH & WITHOUT CONTRAST
72148	MRI LUMBAR SPINE WITHOUT CONTRAST
72149	MRI LUMBAR SPINE WITH CONTRAST
72156	MRI NECK, SPINE WITH & WITHOUT CONTRAST
72157	MRI, THORAX SPINE WITH & WITHOUT CONTRAST
72158	MRI LUMBAR SPINE WITH & WITHOUT CONTRAST
72192	CT PELVIS WITHOUT CONTRAST
72193	CT PELVIS WITH CONTRAST
72194	CT PELVIS WITH & WITHOUT CONTRAST
72195	MRI PELVIS WITHOUT CONTRAST
72197	MRI PELVIS WITH & WITHOUT CONTRAST
74150	CT ABDOMEN WITHOUT CONTRAST
74160	CT ABDOMEN WITH CONTRAST
74170	CT ABDOMEN WITH & WITHOUT CONTRAST
74181	MRI ABDOMEN WITH & WITHOUT CONTRAST
74183	MRI ABD WITH & WITHOUT CONTRAST
74185	MRI ABDOMEN WITH OR WITHOUT CONTRAST
78306	BONE IMAGING WHOLE BODY
78315	BONE IMAGING, THREE PHASE

CPT	Imaging Study
78320	BONE IMAGING, TOMOGRAPHIC
78608	PET BRAIN SINGLE SLICE
78802	TUMOR IMAGING WHOLE BODY
78803	TUMOR LOCALIZATION, TOMOGRAPHIC
78811	TUMOR IMAGING (PET), LIMITED
78812	TUMOR IMAGE (PET)/SKULL BASE TO MID-THIGH
78814	TUMOR IMAGE PET/CT, LIMITED
78815	TUMOR IMAGE PET/CT SKULL BASE TO MID-THIGH
78816	TUMOR IMAGE PET/CT FULL BODY

Appendix Table 5

Analysis of Unweighted Counts of Cancer-related Imaging Studies by Imaging Modality

Study population by cancer type	Per patient count of cancer-related imaging studies						
	Adjusted mean count				Geographic variation in count		
	VA cohort (95% CI)	Medicare cohort (95% CI)	Difference (95% CI)	P value	VA cohort SD (95% CI)	Medicare cohort SD (95% CI)	HRR-level correlation (95% CI)
CT	0.275 (0.231 to 0.318)	0.535 (0.493 to 0.577)	−0.260 (−0.302 to −0.218)	<0.001	0.12 (0.09 to 0.16)	0.12 (0.09 to 0.15)	0.57 (0.22 to 0.79)
PET	0.012 (0.004 to 0.021)	0.062 (0.056 to 0.068)	−0.050 (−0.061 to −0.039)	<0.001	0.03 (0.02 to 0.03)	0.01 (0.01 to 0.02)	−0.25 (−0.58 to 0.16)
Nuclear	0.056 (0.046 to 0.065)	0.150 (0.141 to 0.159)	−0.094 (−0.105 to −0.083)	<0.001	0.03 (0.02 to 0.03)	0.02 (0.02 to 0.03)	0.35 (−0.07 to 0.66)
MRI	0.025 (0.020 to 0.030)	0.045 (0.039 to 0.050)	−0.020 (−0.026 to −0.014)	<0.001	0.01 (0.01 to 0.02)	0.01 (0.01 to 0.02)	0.50 (−0.13 to 0.84)
Ultrasound	0.261 (0.143 to 0.379)	0.425 (0.244 to 0.606)	−0.165 (−0.273 to −0.057)	0.003	0.33 (0.25 to 0.43)	0.54 (0.42 to 0.70)	0.90 (0.72 to 0.97)
X-ray	0.675 (0.613 to 0.738)	0.377 (0.343 to 0.411)	0.298 (0.232 to 0.364)	<0.001	0.13 (0.07 to 0.22)	0.09 (0.07 to 0.12)	0.21 (−0.34 to 0.65)

VA = Veterans Affairs, SD = standard deviation, HRR = hospital referral region, CT = computed tomography, PET = positron emission tomography, MRI = magnetic resonance imaging

Figure 1. Differences in Use of Cancer-related Imaging between Medicare and VA Cohorts by Imaging Modality

Within-region differences in adjusted imaging use between Medicare and VA cohorts are displayed by imaging modality. Error bars indicate 95% confidence intervals.

CT = computed tomography, PET = positron emission tomography, MRI = magnetic resonance imaging

Figure 2. Geographic Variation in Cancer-related Imaging for Medicare vs. VA Cohort

For each cohort, adjusted mean use of cancer-related imaging (mean price-weighted count expressed in dollars per patient) is displayed by HRR, with HRRs ranked separately for each cohort. Error bars indicate 95% confidence intervals. In a sensitivity analysis, exclusion of the HRR with the highest level of use in the VA cohort did not alter conclusions.

Table 1

Within-region Comparisons of Sociodemographic and Clinical Characteristics between Medicare and VA Patients with Lung, Colorectal, or Prostate Cancer*

Characteristic	Medicare Cohort (N=34,475)	VA Cohort (N=6,835)	P value
<i>All Patients with Lung, Colorectal, or Prostate Cancer</i>			
Age at diagnosis, %, y			<0.001
66–70	26.8	31.2	
71–75	27.7	31.0	
76–80	23.5	22.9	
81–85	14.7	12.1	
86+	7.3	2.8	
Race/ethnicity, %			<0.001
Non-Hispanic White	81.4	72.0	
Non-Hispanic Black	12.0	20.8	
Hispanic	2.1	3.2	
Other	4.8	4.2	
Marital status, %			<0.001
Single	7.4	6.7	
Married	66.6	52.8	
Separated or divorced	6.4	24.0	
Widowed	12.1	13.6	
Unknown	7.5	2.9	
Cancer type, %			<0.001
Lung	28.1	31.9	
Colorectal	18.5	16.8	
Prostate	54.4	52.1	
History of prior cancer, %	15.8	14.1	0.002
Died within the year, %	17.5	17.4	0.83
Charlson comorbidity score, %			<0.001
0	48.5	45.5	
1	25.9	31.2	
2	13.1	13.7	
3+	12.6	9.7	
ZIP code-level characteristics			
Residents aged 65 y with income below federal poverty level, mean %	10.5	11.3	<0.001
Median household income, \$	52,933	47,688	<0.001
Residents with college degree, mean %	30.5	27.1	<0.001
Residents employed in professional occupations, mean %	33.3	30.6	<0.001
Hispanic residents, mean %	12.8	13.8	<0.001
Black residents, mean %	13.4	16.4	<0.001

Patients with Lung Cancer

Characteristic	Medicare Cohort (N=34,475)	VA Cohort (N=6,835)	P value
Small cell, %	12.6	12.7	0.92
Stage, %			<0.001
Limited	69.9	57.0	
Extensive	30.1	43.0	
Non-small cell, %	87.4	87.3	0.92
AJCC stage, %			<0.001
I	19.9	25.5	
II	5.3	6.7	
IIIA	9.6	10.0	
IIIB	16.8	16.0	
IV	38.6	35.4	
Unknown	9.8	6.5	
<i>Patients with Colorectal Cancer</i>			
AJCC stage, %			<0.001
I	26.2	29.3	
II	27.7	25.5	
III	23.2	18.9	
IV	16.5	16.2	
Unknown	6.5	10.1	
Grade, %			<0.001
Well differentiated	9.5	7.4	
Moderately differentiated	63.1	61.6	
Poorly differentiated or undifferentiated	17.3	15.7	
Unknown	10.7	15.8	
<i>Patients with Prostate Cancer</i>			
Grade, %			<0.001
Well differentiated (Gleason score 2–4)	2.2	3.0	
Moderately differentiated (Gleason score 5–6)	53.2	55.1	
Poorly differentiated/undifferentiated (Gleason score 7–10)	41.2	39.7	
Unknown	3.5	2.3	
Metastatic, %	7.3	5.7	< 0.001
T stage for non-metastatic cancer, %			<0.001
T1	43.1	49.7	
T2	50.8	35.6	
T3	2.0	2.5	
Unknown	4.1	12.6	

VA = Veterans Affairs, AJCC = American Joint Committee on Cancer Staging, T = tumor

* All estimates have been adjusted for geography at the level of hospital referral regions (HRRs). To estimate HRR-adjusted cohort means, we fitted a regression model for each value of each listed variable as a function of cohort membership and HRR fixed effects (logistic regression for categorical variables and linear regression for continuous variables). Cohort-specific adjusted means were then calculated from model estimates, holding the geographic distribution of patients constant for both cohorts. These models also provided tests of cohort differences in continuous and dichotomous variables. For statistical tests of differences between cohorts in the distribution of categorical variables with more than two values, for

each characteristic we fitted a logistic regression model for cohort membership as a function of the characteristic (specified categorically) and HRR fixed effects.

Table 2

Cancer-related Imaging Use in VA and Medicare Cohorts by Type of Cancer

Study population	Cancer-related imaging use (price-weighted utilization count in \$/patient)						
	Adjusted mean use			Geographic variation in use			
	VA cohort (95% CI)	Medicare cohort (95% CI)	Difference (95% CI)	P value	VA cohort SD (95% CI)	Medicare cohort SD (95% CI)	HRR-level correlation (95% CI)
All patients							
Lung, colorectal, or prostate cancer (N=41,310)	197 (170 to 225)	379 (357 to 401)	-182 (-208 to -156)	<0.001	78 (60 to 101)	60 (45 to 79)	0.53* (0.17 to 0.76)
Stratified by cancer type							
Lung cancer (N=11,855)	386 (327 to 444)	727 (679 to 775)	-341 (-409 to -274)	<0.001	160 (120 to 213)	124(86 to 178)	0.23 (-0.24 to 0.61)
Colorectal cancer (N=7,523)	323 (288 to 359)	396 (367 to 424)	-73 (-123 to -22)	0.005	58 (24 to 139)	68 (43 to 106)	-0.62 (-0.96 to 0.50)
Prostate cancer (N=22,317)	102 (81 to 123)	240 (219 to 262)	-138 (-156 to -121)	<0.001	57 (43 to 74)	60 (46 to 79)	0.76 (0.47 to 0.90)

VA = Veterans Affairs, SD = standard deviation, HRR = hospital referral region

* A generalized linear mixed model with a log link and proportional to mean variance function produced estimates of adjusted means, the between-cohort difference, and within-cohort geographic variation in cancer-related imaging use that were similar to estimates presented in the table; the HRR-level correlation estimated with this model was somewhat lower (0.37 vs. 0.53).