Potentially preventable intensive care unit admissions in the United States, 2006 - 2015

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Abstract

Rationale: Increasing intensive care unit (ICU) beds and the critical care workforce are often advocated to address an aging and increasingly medically complex population. However, reducing potentially preventable ICU stays may be an alternative to ensure adequate capacity.

Objectives: To determine the proportions of ICU admissions meeting two definitions of being potentially preventable using nationally representative United States (US) claims databases.

Methods: We analyzed claims from 2006 to 2015 from all Medicare Fee-for-Service (FFS) beneficiaries and from a large national payer offering a private plan (PI) and a Medicare Advantage (MA) plan. Potentially preventable hospitalizations were identified using existing definitions for ambulatory care sensitive conditions (ACSC) and life-limiting malignancies (LLM).

Measurements and Main Results: We analyzed 420,369,434 person-years of insurance coverage during which there were 99,793,416 acute inpatient hospitalizations, of which 16,646,977 (16.7%) were associated with an ICU admission. Of these, the proportions with an ACSC were 12.9%, 12.7%, and 15.8%, and with a LLM were 5.2%, 5.4%, and 6.4%, among those with PI, MA, and FFS, respectively. Over 10 years, the absolute percentages of ACSC-associated ICU stays declined (PI -1.1%, MA -6.4%, FFS -6.4%; all P<0.001 for all trends). Smaller changes were noted among LLM-associated ICU stays, declining in the MA cohort (-0.8%) and increasing in the FFS (+0.3%) and PI (+0.2%) populations (P<0.001 for all trends).

Conclusions: An appreciable proportion of US ICU admissions may be preventable with community-based interventions. Investment in the outpatient infrastructure required to prevent these ICU admissions should be considered as a complementary, if not alternative, strategy to expanding ICU capacity to meet future demand.

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Introduction

Admissions to the intensive care unit (ICU) are costly and strain health system resources (1, 2). In the United States (US), the number of critical care beds and their associated costs are increasing (2). Although the total number of ICU admissions appears to be declining over time, there is significant heterogeneity among states (3), and the US still admits more ICU patients than most Western European countries (4). Because ICU admission rates are particularly high among patients 65 years and older (3, 5), and those nearing the end of life (6), the aging and increasingly complex US population may portend a need for increased capacity of critical care delivery services (7, 8).

One potential response to increased demand for critical care services is improved ICU triage and increased interprofessional ICU staffing (9). By contrast, recognizing that some ICU patients may not need, want, or benefit from ICU admission (10–12), another way to meet the growing demand for critical care without increasing costs may be to prevent progression of illnesses that lead to ICU admission (13). However, it is unknown how many ICU admissions are potentially preventable annually in the US. Despite recent attention on preventable hospitalizations (14, 15), little work has explored preventable hospitalizations associated with ICU services (16).

Therefore, we sought to determine the proportion of hospitalizations associated with an ICU admission in the US that fall into one of two types of potentially preventable admissions. Because there is no standard definition of a potentially preventable ICU condition, we chose to focus on hospitalizations with an ICU admission that 1) are associated with an ambulatory care sensitive condition (ACSC), defined as a hospitalization

that may have been avoided with timely and appropriate outpatient care (14, 17, 18); and 2) occur among patients with a life-limiting malignancy (LLM) nearing the end of life, for whom better advance care planning (ACP) or earlier palliative care services may have helped avoid ICU admission (19–24).

Methods

Using the 100% Medicare Provider Analysis and Review (MedPAR) files, we counted all acute care hospitalizations and identified those associated with ICU care from 2006 through 2015 among Medicare fee-for-service (FFS) beneficiaries 65 years and older. We performed the same analysis with claims from patients enrolled in a large, nationally representative Medicare Advantage (MA) plan and those in a private insurance plan using the Optum Insight Clinformatics™ Data Mart. Person-years of coverage were tabulated using each dataset's beneficiary file. The primary reported outcome is the proportion of ICU admissions meeting the criteria described below for an ACSC or LLM. The Institutional Review Board of the University of Pennsylvania approved this study. Preliminary results were previously reported in an abstract (25).

Administrative definitions

ICU care was considered present if at least one revenue center code for intensive care or cardiac care (CCU), but not for intermediate care, was present in the claims for a given hospitalization (26). We identified hospitalizations as potentially preventable if they included administrative codes for an ACSC (18) or a LLM (27). The latest definition of ACSCs encompasses 13 clinical categories of acute and chronic conditions, including

hypertension, urinary tract infection, and uncontrolled diabetes, for which timely outpatient care may have prevented a hospital admission. Details of the development process and construct validity of each ACSC have been previously reported (18). This construct does not identify the direct reason for an ICU admission conditional on an already hospitalized patient. Rather, it identifies hospitalizations that could have been prevented with early outpatient care regardless of whether or not that hospitalization ended up requiring ICU care. The definition of LLMs is based on a clinician-developed palliative care screening program at a large academic cancer center with administrative codes restricted to those with associated high one-year mortality based on Medicare claims data (27). Further details of all administrative definitions are provided in the Digital Supplement.

Temporal trends and group comparisons

We evaluated changes over time for counts and proportions using simple Poisson regression and the chi-squared test for trend, respectively. Confidence intervals and comparisons between observations around observed estimates were reported using Poisson and binomial distributions and tests with a two-sided $\alpha = 0.05$ for counts and proportions, respectively. Comparisons between groups were analyzed with the t-test and chi-square test for continuous and categorical variables, respectively. Additionally, exploratory state-level comparisons are further described in the Supplement. Analytic files were generated from the original databases using SAS (SAS Institute Inc., Cary, NC) and subsequent analyses were performed using the R language for statistical computing version 3.5.0 (28).

Relationship with ICU beds

We measured the correlation between each type of potentially preventable ICU admission and the total number of ICU beds in each state with the FFS population. State indicators were not available for the MA and private insurance populations. Total ICU beds were defined as the number of medical, surgical, and cardiac intensive care beds in each state in a given year based on the American Hospital Association Annual Survey Database (29). We also measured correlations using Spearman's ρ with 95% confidence intervals constructed using 10,000 bootstrap replicates. Differences in correlations were determined by estimating a bootstrapped difference over 10,000 replicates with a two-sided alpha level of 0.05.

Sensitivity analysis

Medical billing procedures in the US utilized International Classification of Diseases Ninth Revision, Clinical Modification (ICD-9-CM) diagnostic and procedure codes through the third quarter of 2015, after which ICD-10 codes were used. Because this transition in coding occurred during our study period, and could confound results based on differences in coding practices and administrative definitions (30), we compared the proportions of each type of potentially preventable ICU admission between the fourth quarters of 2014 and 2015. We then projected the 2015 fourth quarter rates forward based on the 2014 fourth quarter rates and repeated the analyses of temporal trends using the projected rates.

Results

We analyzed 420,369,434 person-years of insurance coverage during which there were 99,793,416 acute inpatient hospitalizations, of which 16,646,977 (16.7%) were associated with an ICU (including CCU) admission (Table 1). The unadjusted incidence of ICU admission and overall hospitalization varied across payer groups (P<0.001 for all comparisons). ICU admission rates were highest in the FFS population (5,110 per 100,000 person-years) and lowest among the privately insured (1,052 per 100,000 person-years).

Among hospitalizations with ICU care, more than 2,580,378 (15.5%) were associated with a potentially preventable diagnosis (Figure 1). Over the course of the ten-year study period, this is equivalent to an average of 258,037 potentially preventable ICU admissions per year.

Relationship with ICU Beds

After adjustment for state demographics and available ICU beds, there is an almost 8-fold difference among states in the rates of ICU admissions (Figure 3). We found significant correlations between each type of ICU admission and the total number of ICU beds in each state (Supplemental Figure E1). For example, in 2015 the correlations between ACSCs (ρ 0.54 , 95% CI 0.26 to 0.73) and LLMs (ρ 0.61, 95% CI 0.38 to 0.76) with ICU beds were similar to that for all ICU admissions (ρ 0.58, 95% CI 0.30 to 0.78). This pattern was consistent across the study period for both ACSCs (Supplemental Figure E2) and LLMs (Supplemental Figure E3).

We observed wide variation in unadjusted ICU admitting patterns across states for ACSCs (Supplemental Figure E4) and LLMs (Supplemental Figure E5). Among states, admission rates per capita for ACSCs and LLMs were positively correlated, whereas these rates were negatively correlated when expressed as percentages of all ICU admissions (Supplemental Figure E6).

Temporal trends

The percentages of ACSC hospitalizations both with and without ICU care declined between 2006 and 2015 across all payer groups (P<0.001 for all tests; Figure 2). In contrast, the percentages of hospitalizations with LLMs showed more heterogeneous trends over time. Over the 10-year period, the absolute percentages of ACSC-associated ICU stays declined across all payer groups (PI -1.1%, MA -6.4%, FFS -6.4%; P<0.001 for all trends). Smaller changes were noted among LLM-associated ICU stays, declining in the MA cohort (-0.8%) and increasing in the FFS (+0.3%) and PI (+0.2%) populations (P<0.001 for all trends).

Age and payer comparisons

The proportion of hospital admissions with ICU care that were potentially preventable varied by age (Figure 4). Among those at least 65 years old, the proportion of hospitalizations with ICU care associated with an ACSC increased with age while those for a LLM declined with age across all payer groups (P<0.001). Among the privately insured, the proportion of potentially preventable hospitalizations with an ICU admission was higher than for hospitalizations without an ICU admission. This difference from the other payer

groups was primarily driven by admission patterns among patients younger than 65 years of age (Supplemental Figure E8).

Sensitivity analysis

The sensitivity analysis examining the effect of new administrative definitions in the fourth quarter of 2015 revealed substantial differences between the observed and projected ICU admission rates (Supplemental Figure E7). In nearly all cases, the observed rates were much lower than the projected rates. However, regardless of the approach used to quantify 2015 fourth-quarter rates, the ten-year trends over the study period were unchanged.

Discussion

Understanding which types of ICU admissions may be preventable is important due to increasing strains on ICU capacity and changes in healthcare financing that prioritize outpatient management. Because a gold standard definition of the "preventability" of hospital or ICU admissions remains elusive (31–33), a focus on admissions with specific potentially preventable mechanisms may elucidate targets for policy and care management interventions that improve the cost-effectiveness of care delivery. Additionally, describing the burden of potentially preventable hospitalizations associated with ICU care would help to inform decisions about modifying the critical care workforce capacity. These results are based on datasets that represent about 13% of the entire US population and about 64% of the US population at least 65 years old.

While the proportion of ICU-associated hospitalizations with an ACSC has been slowly decreasing over time, the proportion of those with a LLM has been increasing. These

divergent trends may reflect known changes in coding practices such as increased billing for sepsis that may mask otherwise equivalent admissions for ACSCs (34, 35) Such patterns may also be explained by changes in population health management and care strategies, attributed to federal reimbursement programs or due to other secular trends (36, 37). By contrast, there have been fewer changes in federal policy to incentivize ACP among patients with LLM, and even recent federal reimbursements for ACP are rarely used (38, 39).

In this context, we found that the proportion of ICU admissions that may be potentially preventable in the US is substantial, ranging from 16-20% with variation across payer groups. This figure underestimates the total proportion of potentially preventable ICU admissions because we did not address other mechanisms of potentially preventable admissions such as those following opioid overdose (40), firearm-related injuries (41, 42), and motor vehicle collisions due to distracted driving (43) or intoxication (44). The possibility that an appreciable proportion of ICU admissions may be preventable with early, community-based interventions highlights several opportunities for policy change and further study.

First, our results suggest that expansion of ICU bed supply in the US contributes to the total number of potentially preventable ICU admissions, though perhaps not to the proportion of ICU admissions that are potentially preventable. Put another way, ICU-bed elasticity of demand (45) does not differ between admissions for ACSCs, LLMs, and general ICU admissions. Over the last decade, ICU beds in the US increased by 15% to 18% (2, 46). Thus, reversals of this trend, if not outright reductions in ICU bed supply, might similarly

reduce preventable and non-preventable ICU admissions alike. However, since ICU clinicians may become more efficient when faced with bed scarcity (47), triage could change differentially between preventable and non-preventable admissions. Even after adjustment for baseline demographics and available ICU beds, there remains wide variation in the state-level admission rates for potentially preventable ICU admissions. While no optimal ICU admission rate for these diagnoses has been determined, the wide variation likely suggests room to improve appropriate triage and care delivery. Subsequent cost savings could support investment in outpatient services designed to prevent such hospitalizations in the first place.

Second, while ACSCs were generally more common in hospitalizations without an ICU stay among Medicare beneficiaries, rates of ACSCs were still high in hospitalizations with an ICU stay. By contrast, among privately insured patients, ACSC and LLM rates were higher in hospitalizations with an ICU stay, mostly among those 15 to 50 years of age. We could not determine if the differences in this younger cohort were driven by variation in administrative coding practices in a younger, less complex population, by triage differences within hospitals, or other reasons. Even so, our national estimates align with the one prior study on this topic from a single center (16). This is an important finding because historical efforts to reduce admissions for ACSCs have ignored ICU status, which is associated with significantly higher costs (48, 49). Estimated costs for hospitalizations with ICU care far exceed those for corresponding outpatient preventive services (50). Targeting prevention of hospitalizations with an ICU stay are more likely to be cost effective or even cost saving overall compared to targeting hospitalizations without an ICU stay. However, evaluation of cost sharing under different payment plans is warranted to evaluate the potential impact

on patients and families who may incur out-of-pocket or informal costs associated with more outpatient or home services.

Third, the appreciable rates of ICU admissions among patients with LLM also highlight opportunities to improve preference-concordant care. We found that 6.3% of all ICU admissions are among patients with malignancies with limited expected survival, but many other seriously ill patients with similar prognoses, such as those with chronic lung disease (51), heart failure (52), and neurodegenerative disorders (20), also spend significant time in the ICU near the end of life. Prior work has shown that national ICU bed supply is associated with the proportion of patients dying with cancer who are admitted to the ICU near the end of life (53), and similar associations are likely for these other groups of seriously ill patients. Early palliative care in patients with serious illness may reduce ICU admissions and costs, while simultaneously improving patient- and family-centered outcomes (19, 21–24). Thus, greater investment in early, outpatient palliative care may be both cost-saving and quality-enhancing compared with investment in ICU bed and workforce expansion.

Fourth, although based on an exploratory analysis, regional differences in ICU utilization patterns for ACSCs and LLMs highlight potentially important heterogeneity in demographic patterns, severity of illness, and ICU triage decisions. Puerto Rico, for example, had the highest proportion of ICU admissions for ACSCs but the lowest for LLMs, indicating that the ICU may play a different role in health systems with fewer trained intensivists and a more limited primary care infrastructure (54, 55). In a previous study of 7 US states, Medicaid expansion was associated with decreased rates of mechanical ventilation in select

populations (56). This preliminary finding suggests that for some diseases and in some regions, expanded primary care access may reduce the incidence of severe respiratory failure. Decisions to expand ICU capacity based on admission rates should account for both the potential preventability of ICU admissions and also the needs of the local health system outside of the ICU.

This study should be interpreted in light of its limitations. First, the assessment of "preventability" (33) or "goal concordance" (57, 58) is difficult even with manual chart review and is further confounded when using only administrative claims. At the individual patient level, preventability for ACSCs and LLMs is probably best determined through a mixed-methods analysis that accounts for both patient preferences for care and local availability of relevant care delivery services — neither of which were examined in this study (17, 31). Additionally, although ACSCs have previously been evaluated in hospitalizations with an ICU stay, it has only been in aggregate with those hospitalizations without an ICU stay. The fact that ACSCs (including those requiring the presence of a primary diagnosis) were still found in some hospitalizations even in the presence of an ICU admission may increase confidence in prominent role of that diagnosis. This approach also does not distinguish between a hospitalization that could have been prevented entirely and one that would only have required ward-level, rather than ICU-level, care with an earlier community-based intervention. The difference between these two cases highlights the need for defining and evaluating both the constructs of "preventable ICU admissions" and "preventable hospitalizations associated with an ICU admission." Thus, we avoided making claims of the preventability of any individual hospitalization, but rather focused on population-level groups of potentially preventable hospitalizations. Although the rates we

report may therefore be imprecise, the consistently high proportions of potentially preventable admissions across time and payer suggest ample opportunities for improvement.

Second, there is significant heterogeneity in ICU triage decisions across hospitals (59) and hospital referral regions (60) that cannot be accounted for in this study. Thus, it will be important to ascertain how strategies to reduce potentially preventable ICU admissions may work differentially well across settings. Third, other than age and gender, we did not adjust for demographic or other patient-level characteristics across states when calculating hospital or ICU admission rates. Fourth, we did not report trends broken down by individual category of ACSCs. Future work that is able to analyze these more granular trends could inform targeting of particular outpatient services Such an analysis would also disaggregate the contributions of rising rates of chronic obstructive pulmonary disease admissions with simultaneously falling rates of pneumonia (61). Fifth, the databases used in this study did not contain unique patient identifiers that would allow for identification of the same patient across multiple insurance plans. This limitation prevents attributing temporal trends in ICU admission rates to potential factors such as plan switching. Finally, due to the datasets available for this analysis, our estimates did not account for people who were uninsured, covered by Medicaid, or had private insurance through a different payer, thus precluding extrapolation of our findings to the entire US population.

With these caveats in mind, this study nonetheless supports a general conclusion that a substantial portion of ICU admissions in the US may be prevented. This finding is important because it points to population-health approaches that may improve care quality while also

alleviating strain on the national critical care delivery system. Investing in outpatient, preventive and palliative services should therefore be viewed as important complementary, if not alternative, strategies to increasing the critical care workforce in seeking to best care for the nation's sickest patients.

Acknowledgements

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Tables

Table 1: Summary characteristics of claims data from three nationally representative insurance plans from 2006 to 2015.

Measure	All	Fee for service	Medicare Advantage	Private Insurance
Total hospitalizations	99,793,416	88,402,008	4,112,550	7,278,858
Person-years of coverage	420,369,434	289,391,447	19,619,445	111,358,542
Total ICU admissions	13,206,444	11,503,628	545,095	1,157,721
Total CCU admission	3,885,634	3,705,677	163,555	16,402
Any ICU or CCU admission	16,646,977	14,787,690	687,318	1,171,969
Age, mean weighted by 5-year bucket				
Population (range)	66 (0-120)	78 (65-120)	77(65-120)	35 (0-120)
Hospitalizations without ICU admission	79	82	79	38
Hospitalizations with ICU admission	78	81	78	50
Total hospitalizations per 100k person-years	23,739	30,548	20,962	6,536
Total ICU or CCU Admissions per 100k person-years	3,960	5,110	3,503	1,052

Figures

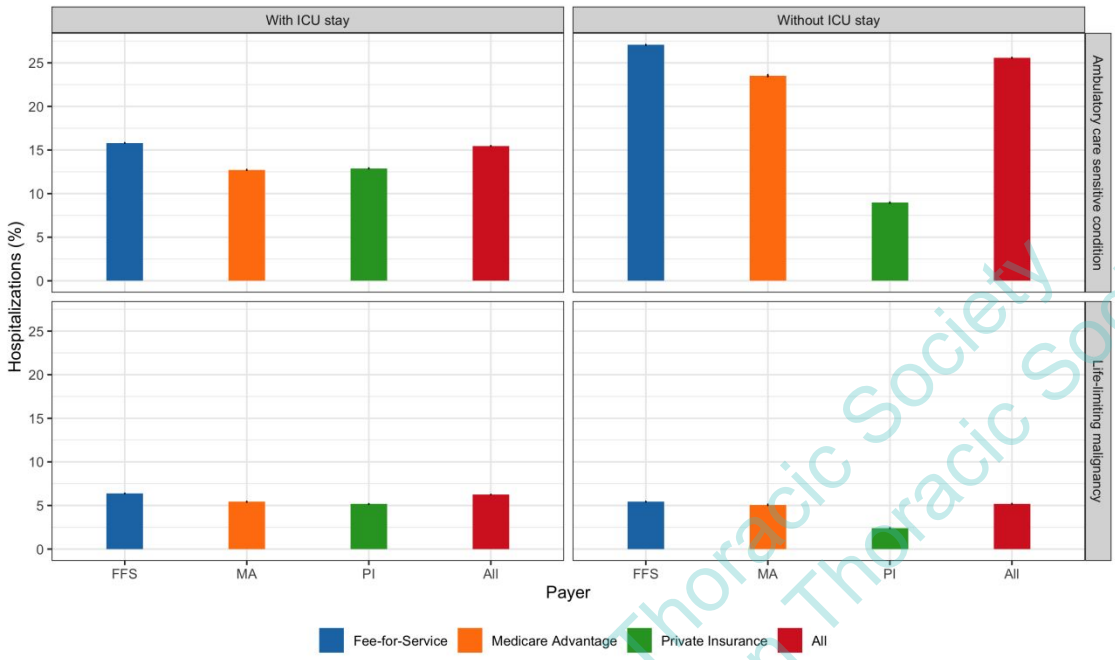

Figure 1: Percentage of hospitalizations, stratified by the presence of an intensive care unit stay and payer, for each potentially preventable condition. Each bar displays the 95% binomial confidence interval. Abbreviations: LLM = life-limiting malignancy, ACSC = ambulatory care sensitive condition.

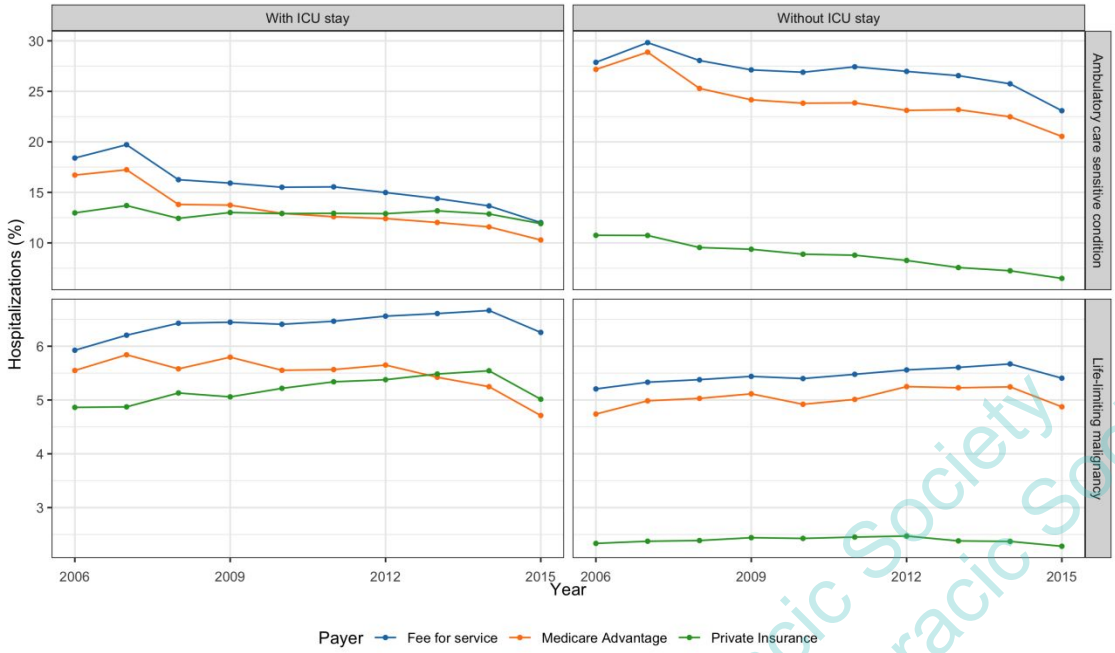

Figure 2: Unadjusted temporal trends in potentially preventable hospitalizations with and without an intensive care unit (ICU) admission in the United States. The plot shows the percentage of admissions by insurance coverage for hospitalizations associated with diagnostic codes for ambulatory care sensitive conditions (top panels) and for life-limiting malignancies (bottom panels).

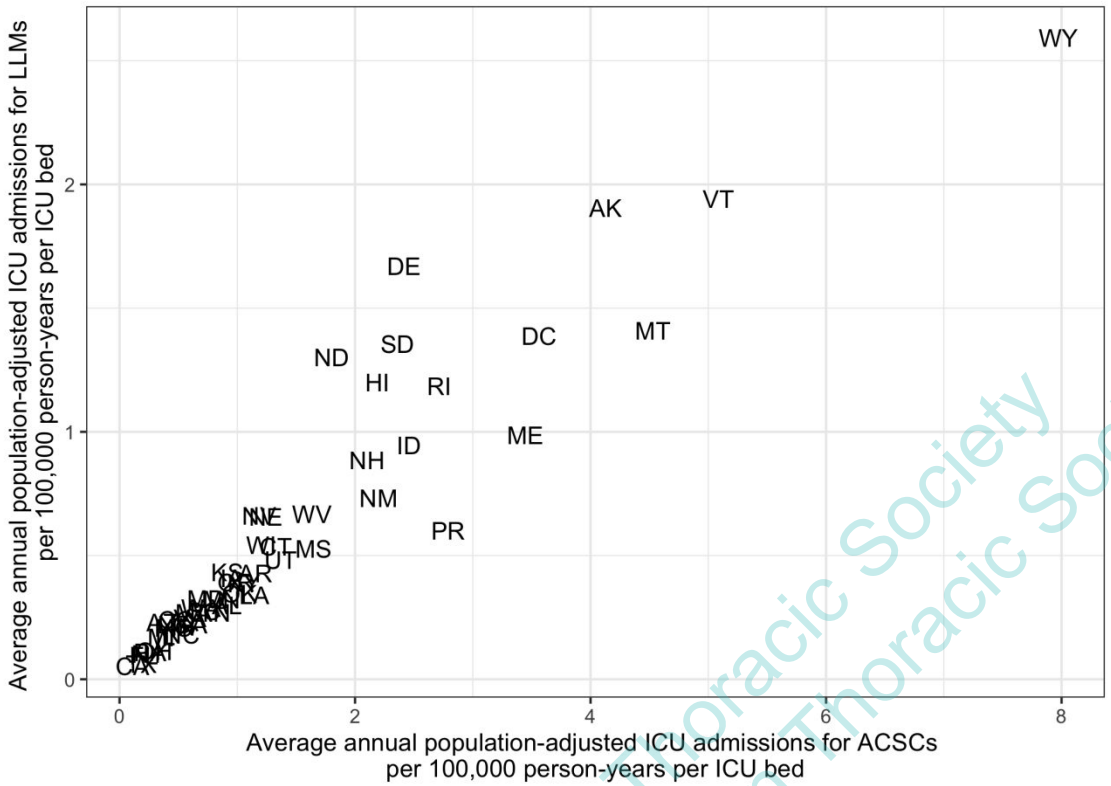

Figure 3: State-level differences in rates of intensive care unit (ICU) admissions for a potentially preventable cause among Medicare-Fee-for-Service beneficiaries at least 65 years old adjusted for the age, gender distribution, and ICU bed capacity in each state, per 100,000 person-years per ICU bed.

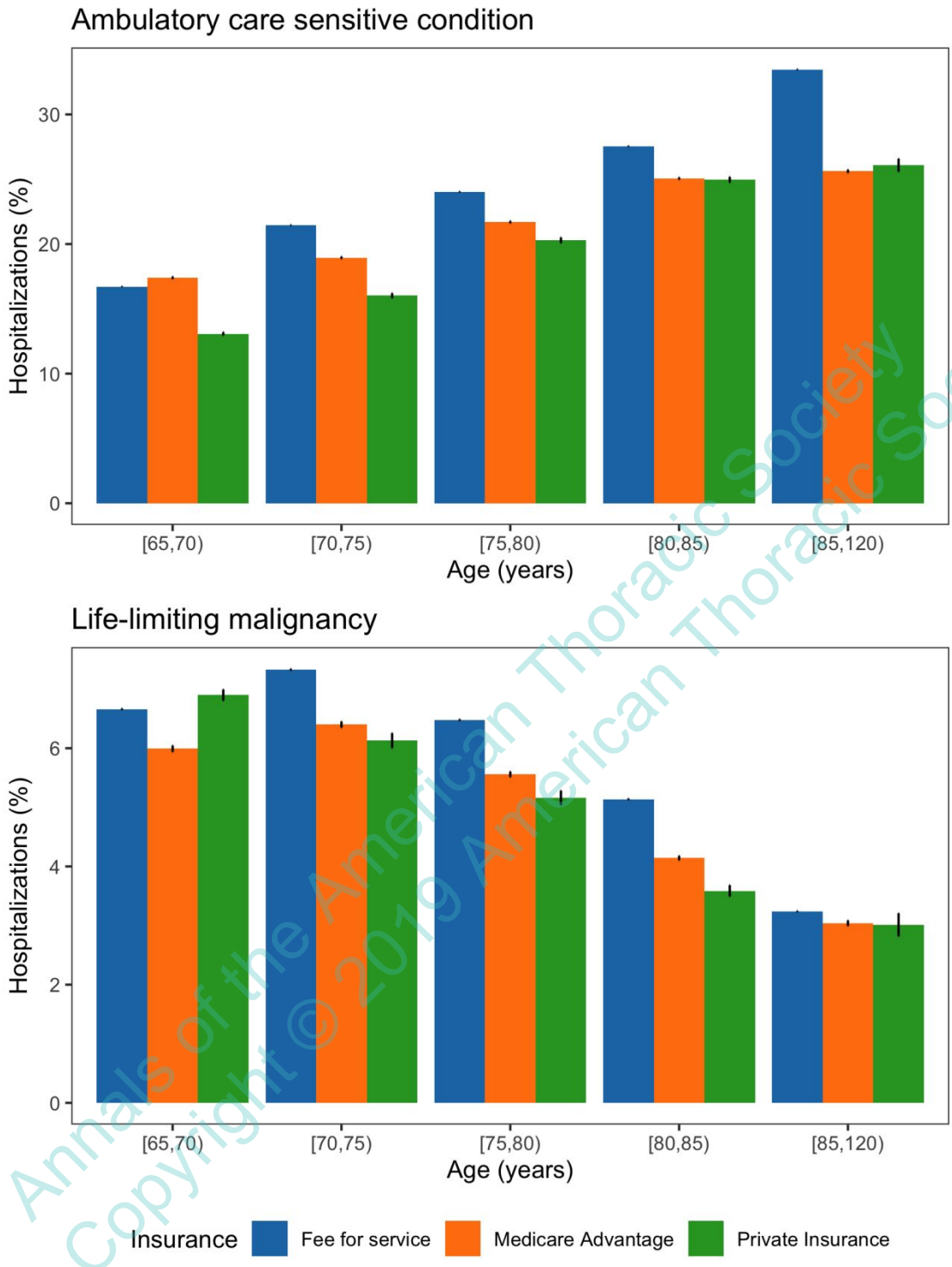

Figure 4: Differences by age in percentage of intensive care unit (ICU) admissions for a potentially preventable cause. The proportion of ICU admissions associated with an ambulatory care sensitive condition increases with age while those with a life-limiting malignancy decreases. These trends are consistent across payer groups. Each bar displays the

95% binomial confidence interval. Brackets indicate a value included in the age interval while parentheses indicate a value excluded from it.

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Digital Supplement: Potentially preventable intensive care unit admissions in the United States, 2006 - 2015

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August 29, 2019

Administrative definitions

Each year of data in each database provided a different number of diagnostic codes. In order to standardize our definitions and minimize classification bias, we used only the first ten diagnostic codes even when more were available.

Intensive care unit stay

Definitions for an intensive care unit (ICU) admission are based on a prior validation study (1). A hospitalization was considered to be associated with ICU care if any of the following revenue center codes was found in the claims: 200, 201, 202, 203, 204, 207, 208, 209, 210, 211, 212, 213, 219. These revenue center codes also correspond in the MedPAR database to ICU indicator codes 0, 1, 2, 3, 4, 7, 8 and 9, and to coronary care indicator codes 0, 1, 2, 3, and 9. Notably, codes for intermediate care units were not considered in this analysis.

Ambulatory care sensitive conditions

Ambulatory care sensitivity conditions were identified based on the published definitions of Prevention Quality Indicators (PQIs) from the Agency for Health Research and Quality (2). Version 5.0 of the definition was used for all claims from 2006 through the third quarter of 2015. Version 6.0 was used in the fourth quarter of 2015 to account for the transition to ICD-10 codes. We used the standard published definitions in all cases except for PQI 13 which was retired in version 6.0 and so was excluded from our definition of version 5.0.

Life-limiting malignancy

Life-limiting malignancy was defined using the published set of ICD-9 codes (Supplemental Table 1) used in a previous study examining eligibility and enrollment in hospice services among cancer patients(3). Since no comparable definition exists for ICD-10 codes, we used the 2016 CMS General Equivalency File to generate a corresponding set of ICD-10-CM codes (Supplemental Table 2). A hospitalization was considered associated with a life-limiting malignancy if any of the reported diagnostic codes were found in the tables below. The code used to generate the ICD-10-CM codes is available online: https://gist.github.com/gweissman/63a162b64969f56b33ce5f6e0c13f51c

Supplemental Table E1: Previously published ICD-9-CM codes associated with a life-limiting malignancy.

ICD-9 Code	Diagnosis
1500	Malignant neoplasm of cervical esophagus
1501	Malignant neoplasm of thoracic esophagus
1502	Malignant neoplasm of abdominal esophagus
1503	Malignant neoplasm of upper third of esophagus
1504	Malignant neoplasm of middle third of esophagus
1505	Malignant neoplasm of lower third of esophagus
1508	Malignant neoplasm of other specified part of esophagus
1509	Malignant neoplasm of esophagus, unspecified site
151	Malignant neoplasm of stomach
1510	Malignant neoplasm of cardia
1511	Malignant neoplasm of pylorus
1512	Malignant neoplasm of pyloric antrum
1513	Malignant neoplasm of fundus of stomach
1514	Malignant neoplasm of body of stomach
1515	Malignant neoplasm of lesser curvature of stomach, unspecified
1516	Malignant neoplasm of greater curvature of stomach, unspecified
1518	Malignant neoplasm of other specified sites of stomach
1519	Malignant neoplasm of stomach, unspecified site
155	Malignant neoplasm of liver and intrahepatic bile ducts
1550	Malignant neoplasm of liver, primary
1551	Malignant neoplasm of intrahepatic bile ducts
1552	Malignant neoplasm of liver, not specified as primary or secondary
1570	Malignant neoplasm of head of pancreas
1571	Malignant neoplasm of body of pancreas
1572	Malignant neoplasm of tail of pancreas
1573	Malignant neoplasm of pancreatic duct
1574	Malignant neoplasm of islets of langerhans
1578	Malignant neoplasm of other specified sites of pancreas
1579	Malignant neoplasm of pancreas, part unspecified
1580	Malignant neoplasm of retroperitoneum
1588	Malignant neoplasm of specified parts of peritoneum
1589	Malignant neoplasm of peritoneum, unspecified

159	Malignant neoplasm of other and ill-defined sites within the digestive organs and peritoneum
1590	Malignant neoplasm of intestinal tract, part unspecified
1591	Malignant neoplasm of spleen, not elsewhere classified
1598	Malignant neoplasm of other sites of digestive system and intra-abdominal organs
1599	Malignant neoplasm of ill-defined sites within the digestive organs and peritoneum
1620	Malignant neoplasm of trachea
1622	Malignant neoplasm of main bronchus
1623	Malignant neoplasm of upper lobe, bronchus or lung
1624	Malignant neoplasm of middle lobe, bronchus or lung
1625	Malignant neoplasm of lower lobe, bronchus or lung
1628	Malignant neoplasm of other parts of bronchus or lung
1629	Malignant neoplasm of bronchus and lung, unspecified
1630	Malignant neoplasm of parietal pleura
1631	Malignant neoplasm of visceral pleura
1638	Malignant neoplasm of other specified sites of pleura
1639	Malignant neoplasm of pleura, unspecified
1641	Malignant neoplasm of heart
1642	Malignant neoplasm of anterior mediastinum
1643	Malignant neoplasm of posterior mediastinum
1648	Malignant neoplasm of other parts of mediastinum
1649	Malignant neoplasm of mediastinum, part unspecified
1650	Malignant neoplasm of upper respiratory tract, part unspecified
1658	Malignant neoplasm of other sites within the respiratory system and intrathoracic organs
1659	Malignant neoplasm of ill-defined sites within the respiratory system
191	Malignant neoplasm of brain
1910	Malignant neoplasm of cerebrum, except lobes and ventricles
1911	Malignant neoplasm of frontal lobe
1912	Malignant neoplasm of temporal lobe
1913	Malignant neoplasm of parietal lobe
1914	Malignant neoplasm of occipital lobe
1915	Malignant neoplasm of ventricles
1916	Malignant neoplasm of cerebellum nos
1917	Malignant neoplasm of brain stem

1918	Malignant neoplasm of other parts of brain
1919	Malignant neoplasm of brain, unspecified
195	Malignant neoplasm of other and ill-defined sites
1951	Malignant neoplasm of thorax
1952	Malignant neoplasm of abdomen
1953	Malignant neoplasm of pelvis
1958	Malignant neoplasm of other specified sites
1973	Secondary malignant neoplasm of other respiratory organs
1974	Secondary malignant neoplasm of small intestine including duodenum
1975	Secondary malignant neoplasm of large intestine and rectum
1976	Secondary malignant neoplasm of retroperitoneum and peritoneum
1977	Malignant neoplasm of liver, secondary
1978	Secondary malignant neoplasm of other digestive organs and spleen
1980	Secondary malignant neoplasm of kidney
1981	Secondary malignant neoplasm of other urinary organs
1982	Secondary malignant neoplasm of skin
1983	Secondary malignant neoplasm of brain and spinal cord
1984	Secondary malignant neoplasm of other parts of nervous system
1985	Secondary malignant neoplasm of bone and bone marrow
1986	Secondary malignant neoplasm of ovary
1987	Secondary malignant neoplasm of adrenal gland
1988	Other specified sites
19881	Secondary malignant neoplasm of breast
19882	Secondary malignant neoplasm of genital organs
19889	Secondary malignant neoplasm of other specified sites
1990	Disseminated malignant neoplasm without specification of site
1991	Other malignant neoplasm without specification of site
1992	Malignant neoplasm associated with transplant organ
20500	Acute myeloid leukemia, without mention of having achieved remission
20502	Acute myeloid leukemia, in relapse
20520	Subacute myeloid leukemia, without mention of having achieved remission
20522	Subacute myeloid leukemia, in relapse
20530	Myeloid sarcoma, without mention of having achieved remission
20532	Myeloid sarcoma, in relapse
20580	Other myeloid leukemia, without mention of having achieved remission
20582	Other myeloid leukemia, in relapse

20590	Unspecified myeloid leukemia, without mention of having achieved remission
20592	Unspecified myeloid leukemia, in relapse
20780	Other specified leukemia, without mention of having achieved remission
20800	Acute leukemia of unspecified cell type, without mention of having achieved remission
20880	Other leukemia of unspecified cell type, without mention of having achieved remission
20890	Unspecified leukemia, without mention of having achieved remission
20892	Unspecified leukemia, in relapse
2375	Neoplasm of uncertain behavior of brain and spinal cord
23873	High grade myelodysplastic syndrome lesions
2391	Neoplasm of unspecified nature of respiratory system
2396	Neoplasm of unspecified nature of brain
78951	Malignant ascites

Supplemental Table E2: Previously published ICD-9-CM codes associated with a life-limiting malignancy converted to corresponding ICD-10-CM codes based on the CMS General Equivalency Mappings.

ICD-10 Code	Diagnosis
C153	Malignant neoplasm of upper third of esophagus
C154	Malignant neoplasm of middle third of esophagus
C155	Malignant neoplasm of lower third of esophagus
C153	Malignant neoplasm of upper third of esophagus
C154	Malignant neoplasm of middle third of esophagus
C155	Malignant neoplasm of lower third of esophagus
C158	Malignant neoplasm of overlapping sites of esophagus
C159	Malignant neoplasm of esophagus, unspecified
C160	Malignant neoplasm of cardia
C164	Malignant neoplasm of pylorus
C163	Malignant neoplasm of pyloric antrum
C161	Malignant neoplasm of fundus of stomach
C162	Malignant neoplasm of body of stomach
C165	Malignant neoplasm of lesser curvature of stomach, unspecified
C166	Malignant neoplasm of greater curvature of stomach, unspecified
C168	Malignant neoplasm of overlapping sites of stomach
C169	Malignant neoplasm of stomach, unspecified
C220	Liver cell carcinoma

C222	Hepatoblastoma
C227	Other specified carcinomas of liver
C228	Malignant neoplasm of liver, primary, unspecified as to type
C221	Intrahepatic bile duct carcinoma
C229	Malignant neoplasm of liver, not specified as primary or secondary
C250	Malignant neoplasm of head of pancreas
C251	Malignant neoplasm of body of pancreas
C252	Malignant neoplasm of tail of pancreas
C253	Malignant neoplasm of pancreatic duct
C254	Malignant neoplasm of endocrine pancreas
C257	Malignant neoplasm of other parts of pancreas
C258	Malignant neoplasm of overlapping sites of pancreas
C259	Malignant neoplasm of pancreas, unspecified
C480	Malignant neoplasm of retroperitoneum
C481	Malignant neoplasm of specified parts of peritoneum
C488	Malignant neoplasm of overlapping sites of retroperitoneum and peritoneum
C482	Malignant neoplasm of peritoneum, unspecified
C260	Malignant neoplasm of intestinal tract, part unspecified
C261	Malignant neoplasm of spleen
C269	Malignant neoplasm of ill-defined sites within the digestive system
C269	Malignant neoplasm of ill-defined sites within the digestive system
C33	Malignant neoplasm of trachea
C3400	Malignant neoplasm of unspecified main bronchus
C3410	Malignant neoplasm of upper lobe, unspecified bronchus or lung
C342	Malignant neoplasm of middle lobe, bronchus or lung
C3430	Malignant neoplasm of lower lobe, unspecified bronchus or lung
C3480	Malignant neoplasm of overlapping sites of unspecified bronchus and lung
C3490	Malignant neoplasm of unspecified part of unspecified bronchus or lung
C384	Malignant neoplasm of pleura
C384	Malignant neoplasm of pleura
C384	Malignant neoplasm of pleura
C384	Malignant neoplasm of pleura
C380	Malignant neoplasm of heart
C381	Malignant neoplasm of anterior mediastinum
C382	Malignant neoplasm of posterior mediastinum
C388	Malignant neoplasm of overlapping sites of heart, mediastinum and pleura

C383	Malignant neoplasm of mediastinum, part unspecified
C390	Malignant neoplasm of upper respiratory tract, part unspecified
C399	Malignant neoplasm of lower respiratory tract, part unspecified
C399	Malignant neoplasm of lower respiratory tract, part unspecified
C710	Malignant neoplasm of cerebrum, except lobes and ventricles
C711	Malignant neoplasm of frontal lobe
C712	Malignant neoplasm of temporal lobe
C713	Malignant neoplasm of parietal lobe
C714	Malignant neoplasm of occipital lobe
C715	Malignant neoplasm of cerebral ventricle
C716	Malignant neoplasm of cerebellum
C717	Malignant neoplasm of brain stem
C718	Malignant neoplasm of overlapping sites of brain
C719	Malignant neoplasm of brain, unspecified
C761	Malignant neoplasm of thorax
C762	Malignant neoplasm of abdomen
C763	Malignant neoplasm of pelvis
C768	Malignant neoplasm of other specified ill-defined sites
C7839	Secondary malignant neoplasm of other respiratory organs
C784	Secondary malignant neoplasm of small intestine
C785	Secondary malignant neoplasm of large intestine and rectum
C786	Secondary malignant neoplasm of retroperitoneum and peritoneum
C787	Secondary malignant neoplasm of liver and intrahepatic bile duct
C787	Secondary malignant neoplasm of liver and intrahepatic bile duct
C7889	Secondary malignant neoplasm of other digestive organs
C7900	Secondary malignant neoplasm of unspecified kidney and renal pelvis
C7911	Secondary malignant neoplasm of bladder
C7919	Secondary malignant neoplasm of other urinary organs
C792	Secondary malignant neoplasm of skin
C7931	Secondary malignant neoplasm of brain
C7932	Secondary malignant neoplasm of cerebral meninges
C7949	Secondary malignant neoplasm of other parts of nervous system
C7951	Secondary malignant neoplasm of bone
C7952	Secondary malignant neoplasm of bone marrow
C7960	Secondary malignant neoplasm of unspecified ovary
C7970	Secondary malignant neoplasm of unspecified adrenal gland

C7981	Secondary malignant neoplasm of breast
C7982	Secondary malignant neoplasm of genital organs
C7989	Secondary malignant neoplasm of other specified sites
C800	Disseminated malignant neoplasm, unspecified
C801	Malignant (primary) neoplasm, unspecified
C802	Malignant neoplasm associated with transplanted organ
C9200	Acute myeloblastic leukemia, not having achieved remission
C9240	Acute promyelocytic leukemia, not having achieved remission
C9250	Acute myelomonocytic leukemia, not having achieved remission
C9202	Acute myeloblastic leukemia, in relapse
C9242	Acute promyelocytic leukemia, in relapse
C9252	Acute myelomonocytic leukemia, in relapse
C9220	Atypical chronic myeloid leukemia, BCR/ABL-negative, not having achieved remission
C9222	Atypical chronic myeloid leukemia, BCR/ABL-negative, in relapse
C9230	Myeloid sarcoma, not having achieved remission
C9232	Myeloid sarcoma, in relapse
C92Z0	Other myeloid leukemia not having achieved remission
C92Z2	Other myeloid leukemia, in relapse
C9290	Myeloid leukemia, unspecified, not having achieved remission
C9292	Myeloid leukemia, unspecified in relapse
C9430	Mast cell leukemia not having achieved remission
C9480	Other specified leukemias not having achieved remission
C9500	Acute leukemia of unspecified cell type not having achieved remission
C9590	Leukemia, unspecified not having achieved remission
C9590	Leukemia, unspecified not having achieved remission
C9592	Leukemia, unspecified, in relapse
D432	Neoplasm of uncertain behavior of brain, unspecified
D434	Neoplasm of uncertain behavior of spinal cord
D4622	Refractory anemia with excess of blasts 2
D491	Neoplasm of unspecified behavior of respiratory system
D496	Neoplasm of unspecified behavior of brain
R180	Malignant ascites

Additional Results

Association with ICU Beds

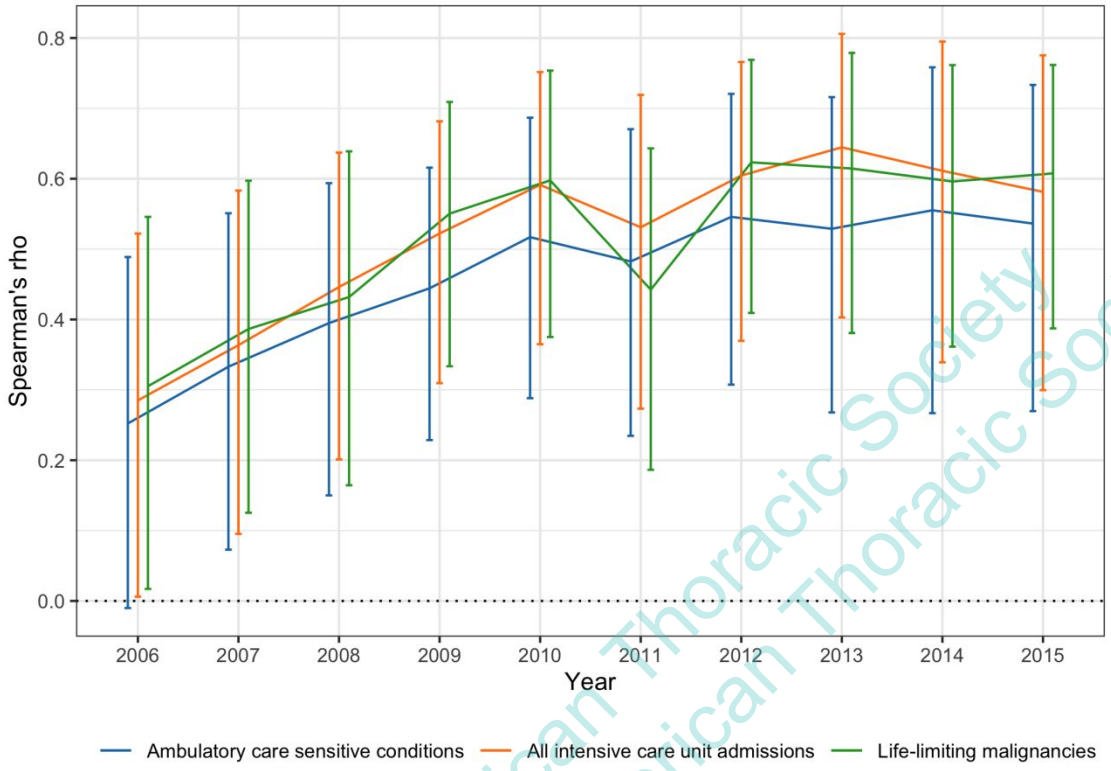

Figure E1: Correlation between available ICU beds and potentially preventable hospitalizations requiring ICU care across states.

The following figures E2 and E3 are presented as a visual check that the bootstrapped distributions of the differences in correlations were roughly normally distributed.

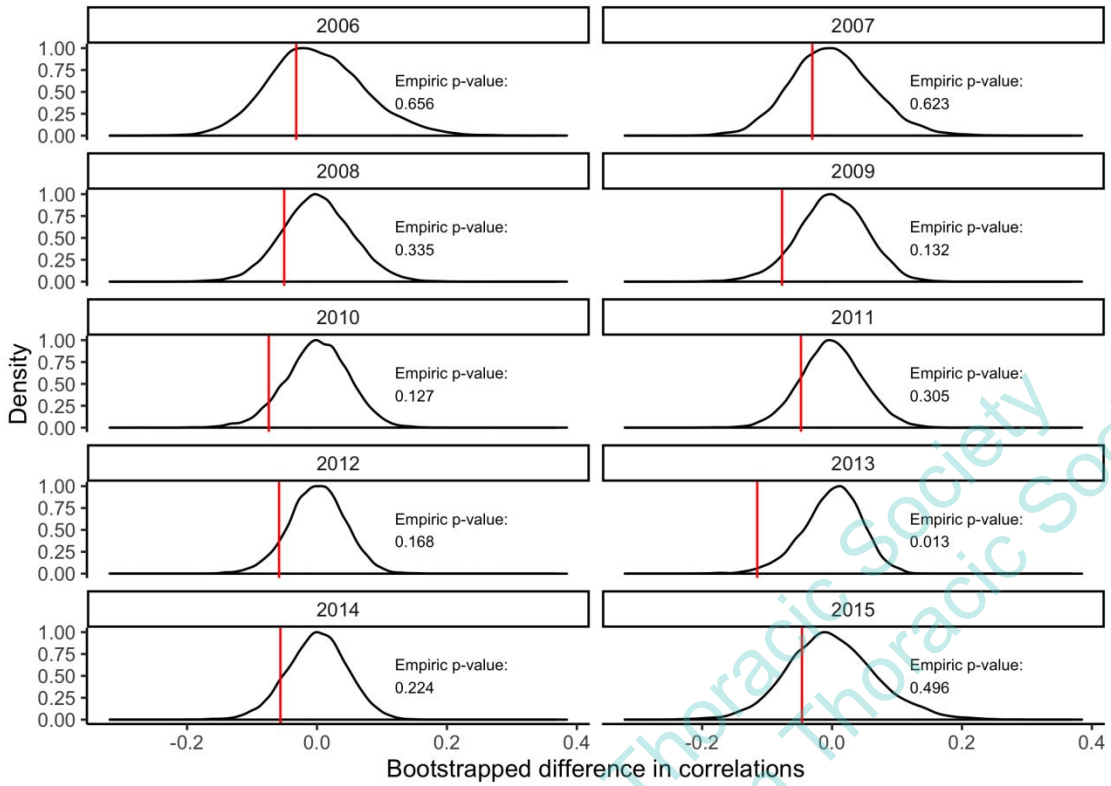

Figure E2: A bootstrapped estimate of the difference between correlation between ICU beds and all ICU admissions, and between ICU beds and ICU admissions associated with ACSC was calculated with 10,000 replicates. The distribution of differences between these values was mean-normalized across each year.

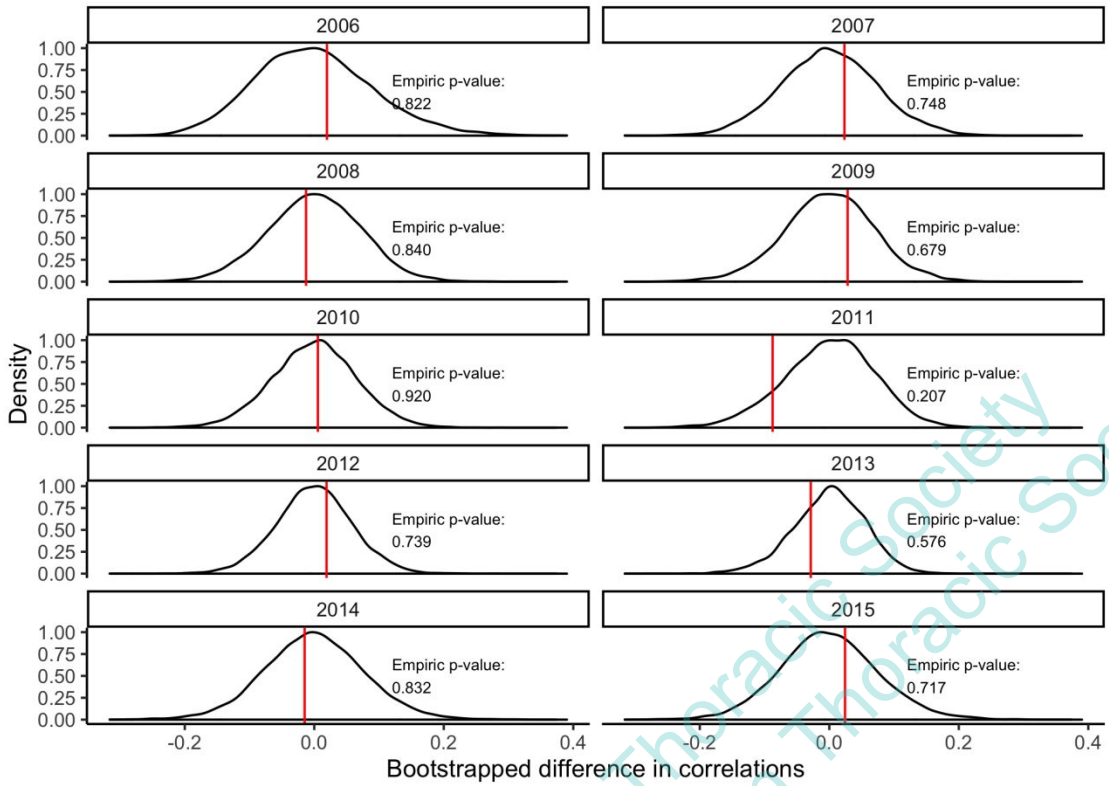

Figure E3: A bootstrapped estimate of the difference between correlations between ICU beds and all ICU admissions, and between ICU beds and ICU admissions associated with LLMs was calculated with 10,000 replicates. The distribution of differences between these values was mean-normalized across each year.

State comparisons

We calculated geographic differences at the state level (including Washington, DC, and Puerto Rico) in the MedPAR database. For between-state comparisons, we adjusted admission rates based on 2010 US Census data for each states' population distribution of age and gender (4). We identified the quintile of states with the lowest proportion of ICU admissions associated with each potentially preventable diagnosis. The following figures E4 and E5 demonstrate the state-level heterogeneity in admission rates, and use the lowest-admitting states to provide a conservative reference point for what a hypothetical floor on such a value might look like.

We observed a two-fold variation among states in potentially preventable ICU admissions in the FFS population (XXX). Among hospitalizations with ICU care, the average proportion with an ACSC ranged from 9.2% (95% CI 8.9 - 9.6) in North Dakota to 21.4% (95% CI 21.0 - 21.8) in Puerto Rico. The average proportion of hospitalizations with ICU care associated with a LLM ranged from 3.9% (95% CI 3.7 - 4.1) in Puerto Rico to 7.6% (95% CI 7.3 - 7.9) in Delaware.

Among hospitalizations associated with an ICU admission in the lowest quintile of states by ICU admission rates in the FFS population, 11.8% were for ACSCs (Supplemental Figure E4)

and 5.0% for LLMs (Supplemental Figure E5). If these estimates represented a lower-bound on achievable admission rates, we would still have observed 59,024 and 19,581 average yearly preventable hospital admissions with ICU care in the remaining states for ACSCs and LLMs, respectively.

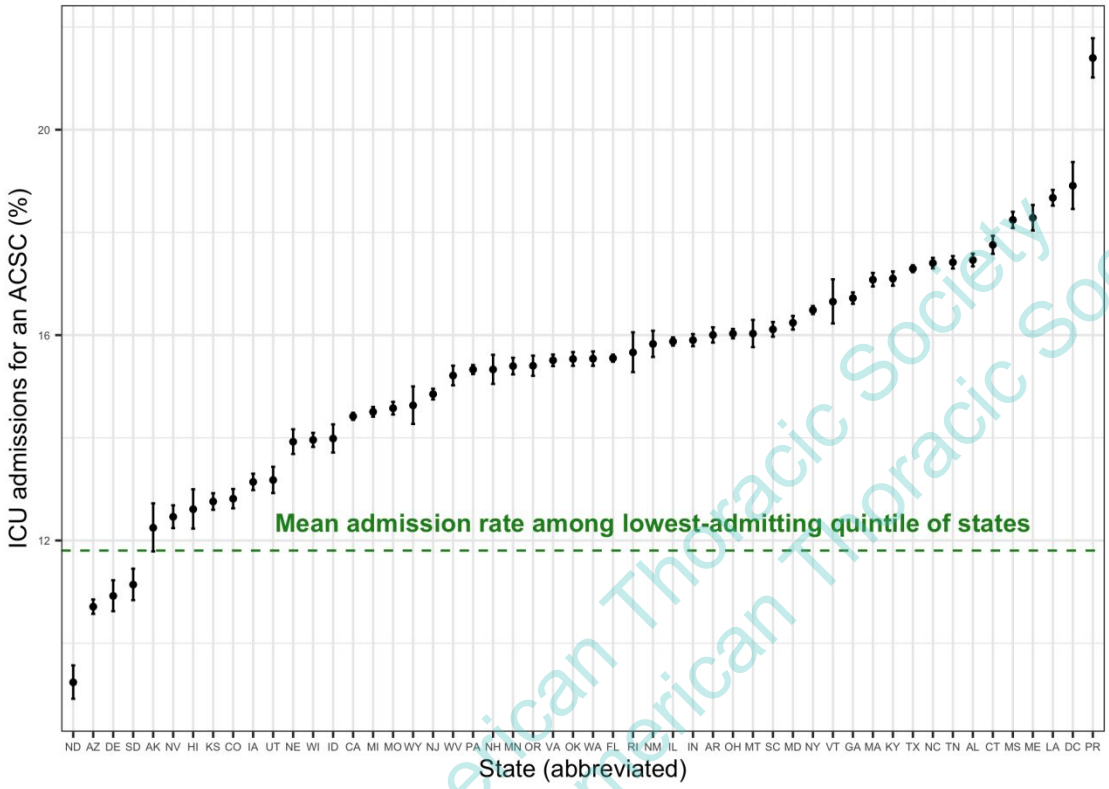

Figure E4: Variation in the percentage of intensive care unit (ICU)-associated hospitalizations with administrative codes for ambulatory care sensitive conditions (ACSCs). Green dotted line indicates the mean admission rate among the lowest-admitting quintile of states.

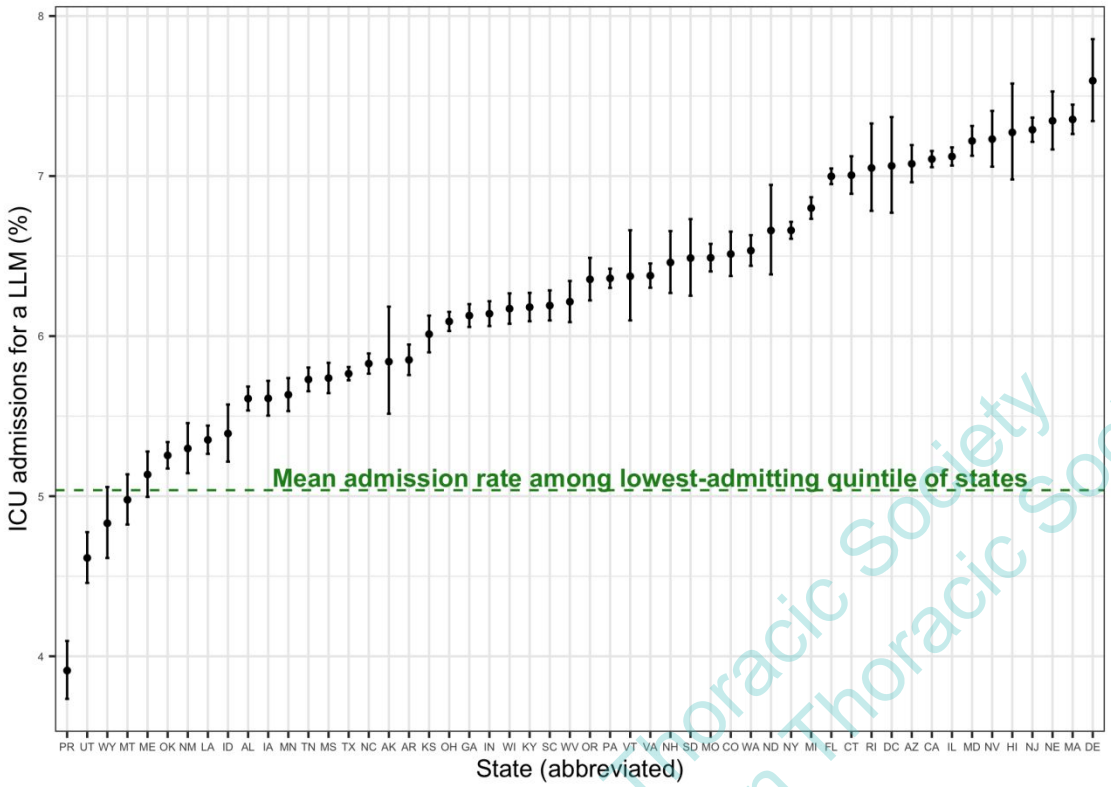

Figure E5: Variation in the percentage of intensive care unit (ICU)-associated hospitalizations with administrative codes for life-limiting malignancies (LLMs). Green dotted line indicates the mean admission rate among the lowest-admitting quintile of states.

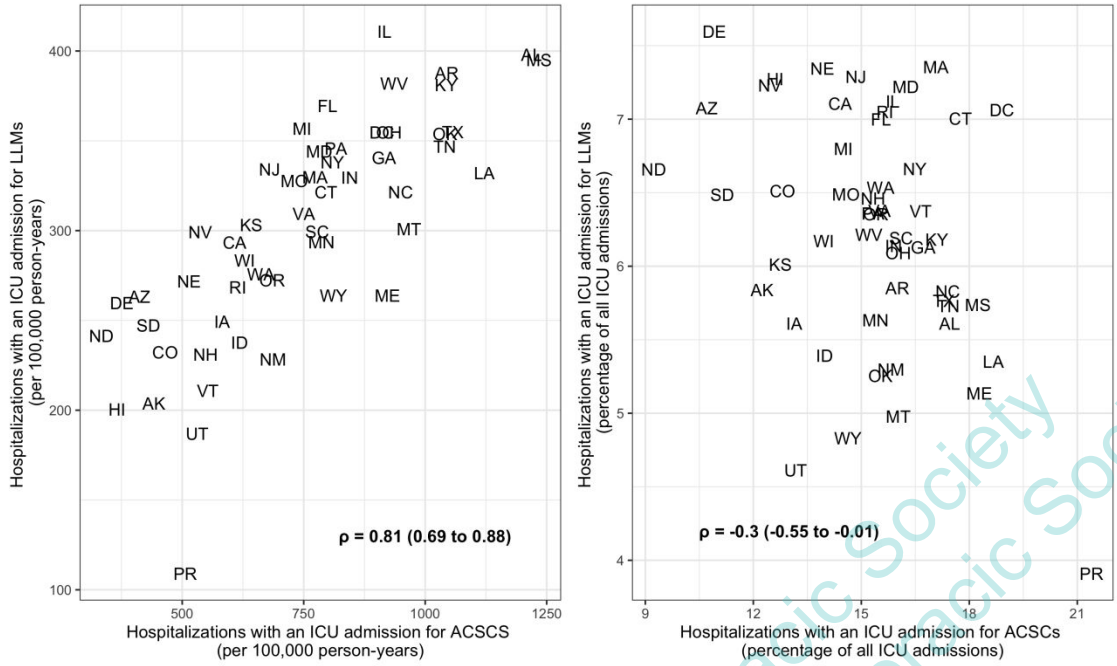

Figure E6: State-level differences in rates of intensive care unit (ICU) admissions for a potentially preventable cause among Medicare Fee-for-Service beneficiaries at least 65 years old adjusted for the age and gender distribution in each state (left panel), and as an unadjusted percentage of all ICU admissions (right panel). The y-axis shows admissions for life-limiting malignancies (LLMs) and the x-axis shows those for ambulatory care sensitive conditions (ACSCs). Correlations represent averages over the ten-year study period. Notably, state populations change relatively little while available ICU beds for admissions change rapidly and heterogeneously across states.

Sensitivity analysis

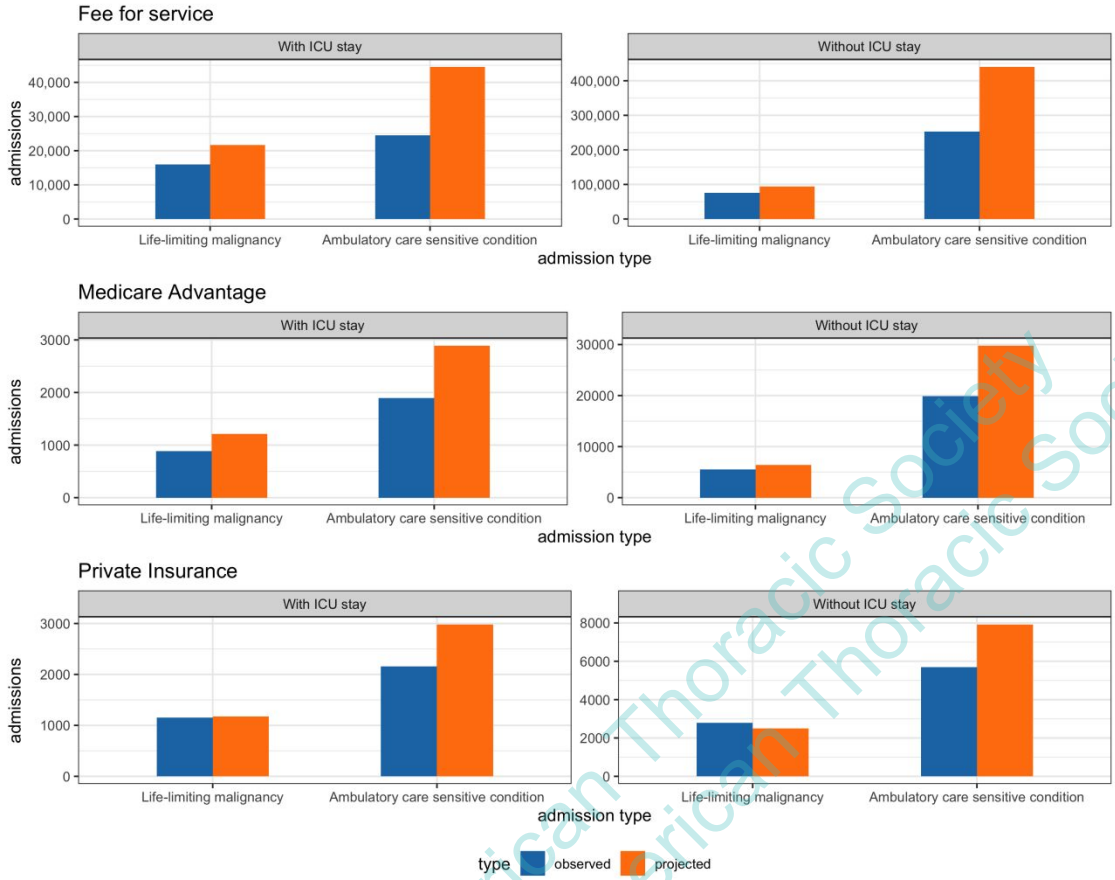

Figure E7: Sensitivity analysis results. Comparison of the observed and projected admission types in the fourth quarter of 2015. While observed and projected admissions differed substantially, the overall ten-year trends when calculated using the projected rates did not meaningfully differ.

Admissions by age among those with private insurance

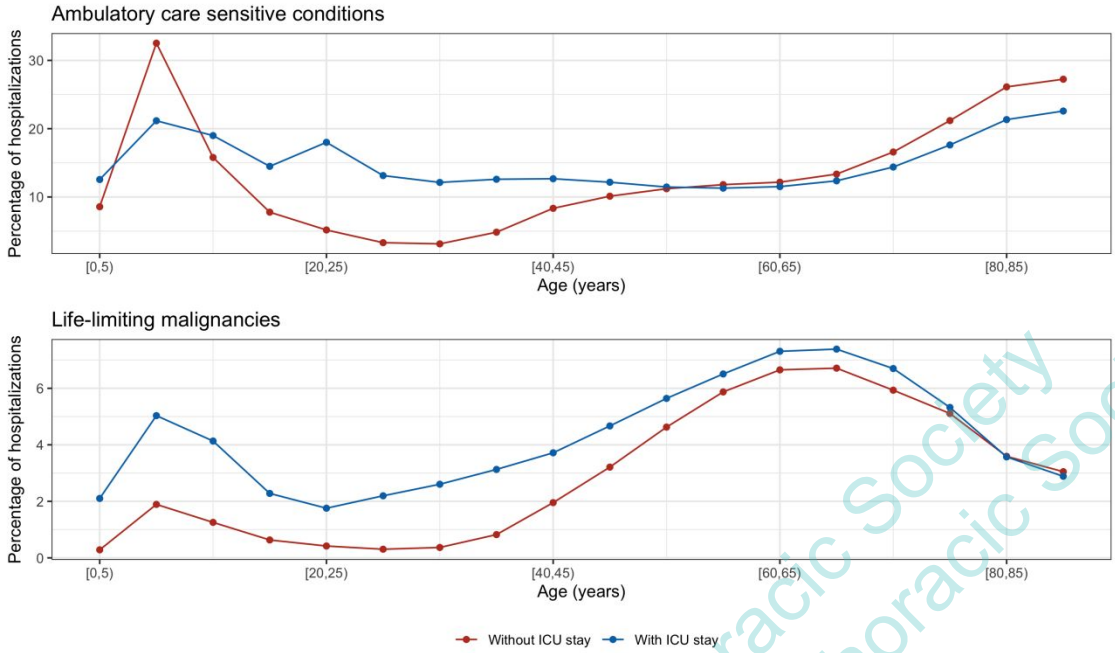

Figure E8: Among those with private insurance, the proportion of potentially preventable hospitalizations by age, stratfied by whether or not the hospitalization was associated with an intensive care unit (ICU) stay. Notably, the privately insured cohort includes patients from newborns through age 65, in addition to those over 65.

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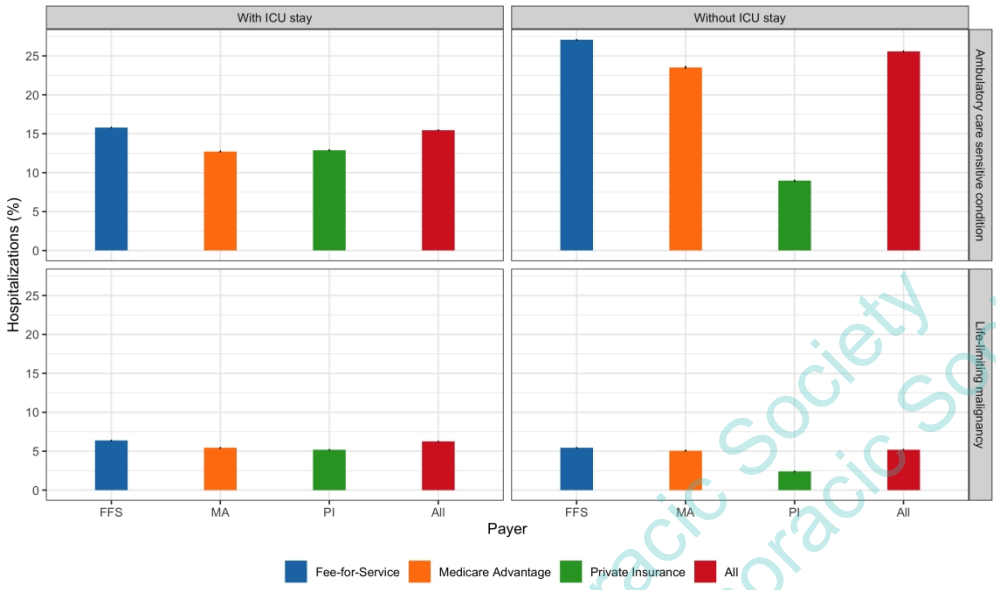
4. US Census Bureau PD. Annual Estimates of the Resident Population for Selected Age Groups by Sex for the United States, States, Counties, and Puerto Rico Commonwealth and Municipios: April 1, 2010 to July 1, 2014. 2015;



Percentage of hospitalizations, stratified by the presence of an intensive care unit stay and payer, for each potentially preventable condition. Each bar displays the 95% binomial confidence interval. Abbreviations: LLM = life-limiting malignancy, ACSC = ambulatory care sensitive condition.

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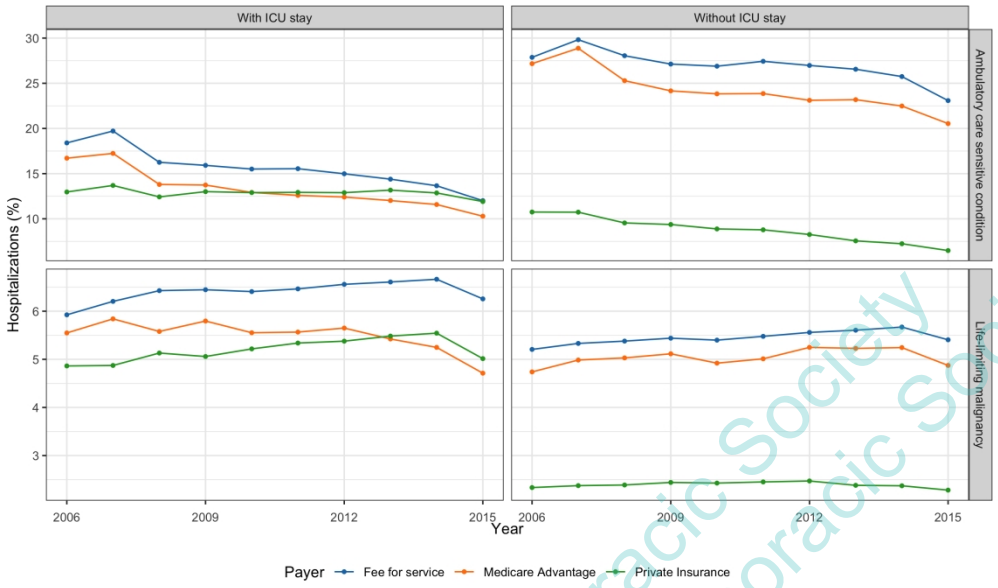

Unadjusted temporal trends in potentially preventable hospitalizations with and without an intensive care unit (ICU) admission in the United States. The plot shows the percentage of admissions by insurance coverage for hospitalizations associated with diagnostic codes for ambulatory care sensitive conditions (top panels) and for life-limiting malignancies (bottom panels).

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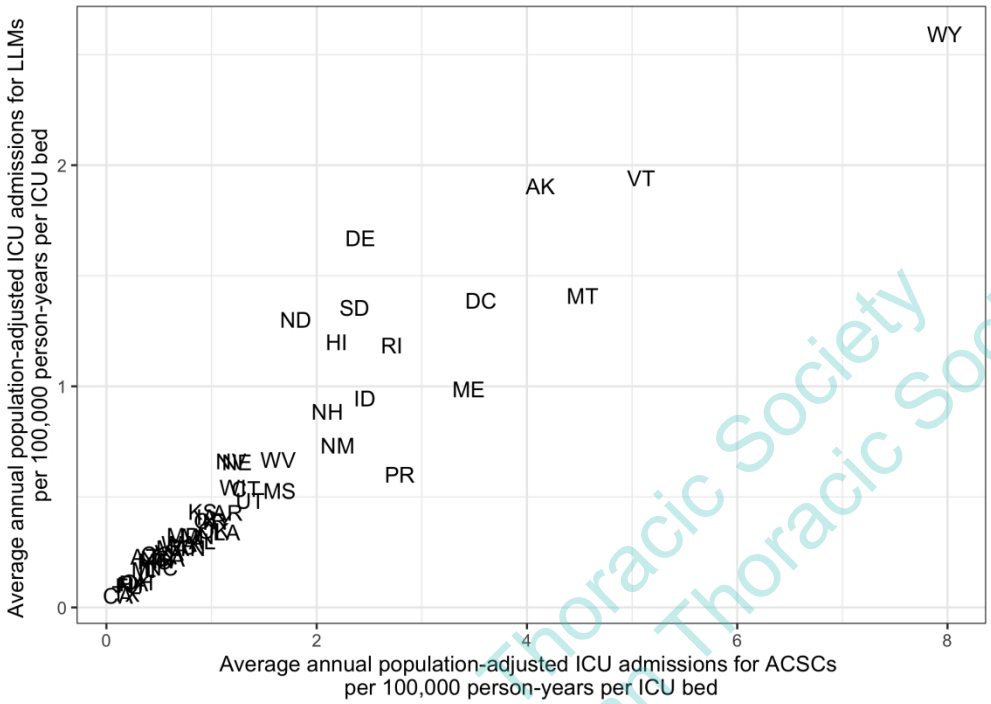

State-level differences in rates of intensive care unit (ICU) admissions for a potentially preventable cause among Medicare-Fee-for-Service beneficiaries at least 65 years old adjusted for the age, gender distribution, and ICU bed capacity in each state, per 100,000 person-years per ICU bed.

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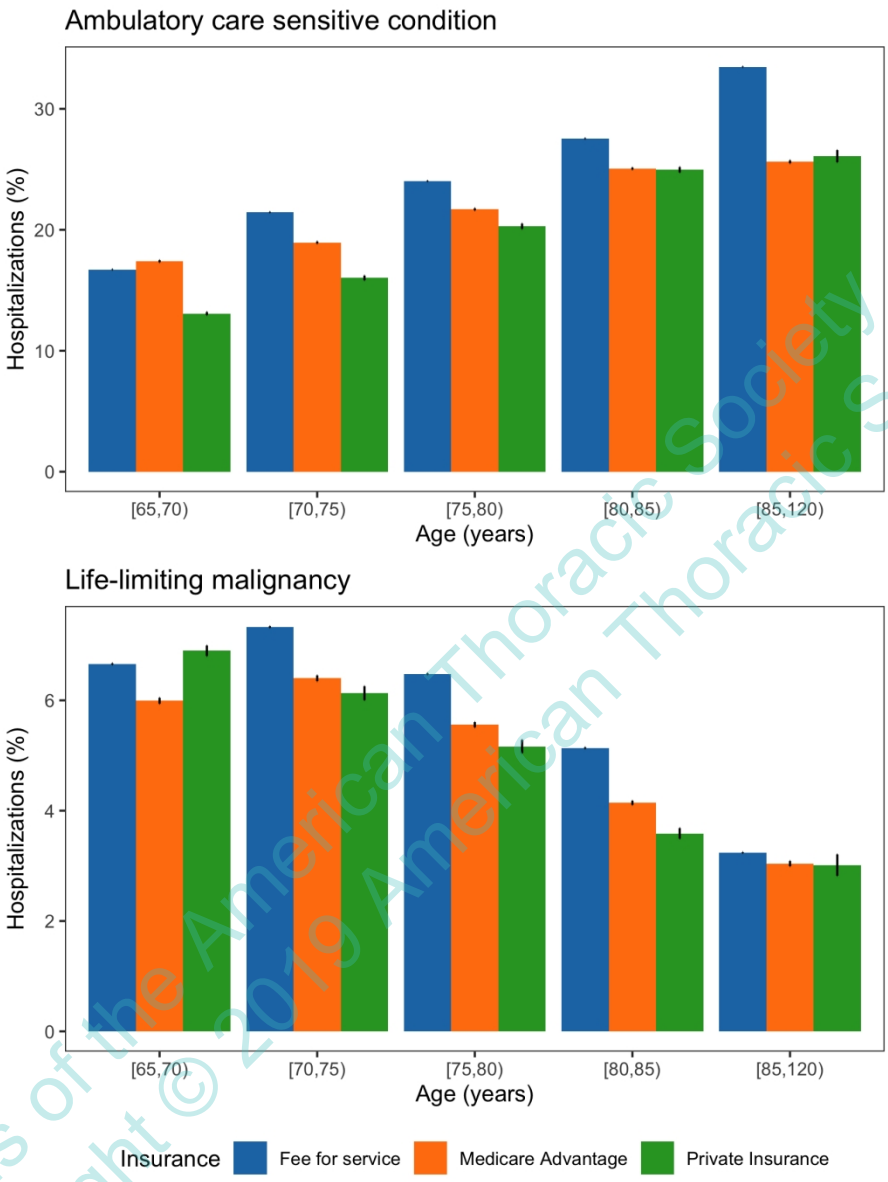

Differences by age in percentage of intensive care unit (ICU) admissions for a potentially preventable cause. The proportion of ICU admissions associated with an ambulatory care sensitive condition increases with age while those with a life-limiting malignancy decreases. These trends are consistent across payer groups. Each bar displays the 95% binomial confidence interval. Brackets indicate a value included in the age interval while parentheses indicate a value excluded from it.

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