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Epidemiological Trends in Invasive Mechanical Ventilation in the United States: A Population-Based Study

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Abstract

Purpose—Epidemiological trends for invasive mechanical ventilation (IMV) have not been clearly defined. We sought to define trends for IMV in the US and assess for disease-specific variation for three common causes of respiratory failure: pneumonia, heart failure (HF), and chronic obstructive pulmonary disease (COPD).

Methods—We calculated national estimates for utilization of non-surgical IMV cases from the Nationwide Inpatient Sample from 1993-2009 and compared trends for COPD, HF, and pneumonia.

Results—We identified 8,309,344 cases of IMV from 1993-2009. Utilization of IMV for non-surgical indications increased from 178.9/100,000 in 1993 to 310.9/100,000 US adults in 2009. Pneumonia cases requiring IMV showed the largest increase (103.6%), whereas COPD cases remained relatively stable (2.5% increase) and HF cases decreased by 55.4%. Similar demographic and clinical changes were observed for pneumonia, COPD, and HF, with cases of IMV becoming younger, more ethnically diverse, and more frequently insured by Medicaid. Outcome trends for patients differed based on diagnosis. Adjusted hospital mortality decreased over time for cases of pneumonia (OR per 5 years=0.89, 95% CI 0.88-0.90) and COPD (OR per 5 years=0.97, 95% CI 0.97-0.98) but increased for HF (OR per 5 years=1.10, 95% CI 1.09-1.12).

Conclusion—Utilization of IMV in the US increased from 1993-2009 with a decrease in overall mortality. However, trends in utilization and outcomes of IMV differed markedly based on

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diagnosis. Unlike favorable outcome trends in pneumonia and COPD, hospital mortality for HF has not improved. Further studies to investigate the outcome gap between HF and other causes of respiratory failure are needed.

Keywords

Mortality/Trends; Epidemiology; Respiratory Insufficiency/Mortality; Respiratory Insufficiency/epidemiology; United States/epidemiology

Introduction

Respiratory support with invasive mechanical ventilation (IMV) remains a cornerstone of critical care medicine. Although frequently a life-saving intervention, non-surgical patients requiring IMV have hospital mortality exceeding 35%.[1-5] Additionally, survivors of IMV may experience significant long-term morbidity with substantially reduced functional status and ability to complete activities of daily living.[6,7] Patients requiring IMV represent 2.8% of hospital admissions, but contribute to 12% of hospital costs at $27 billion per year.[8]

Despite high mortality, morbidity, and costs, trends in utilization and outcomes of IMV in the United States are unclear. Point prevalence studies have suggested that hospital mortality for IMV is improving internationally.[1,2,9] Prior studies have analyzed trends in specific subsets of the IMV population and shown decreasing mortality among patients with acute respiratory failure (ARF) of any etiology[10], acute respiratory distress syndrome (ARDS) [11], and chronic obstructive pulmonary disease (COPD).[10,12-14] However, studies investigating longitudinal trends in IMV in the US and outcomes for other common causes of respiratory failure, such as pneumonia and HF, are lacking.

Given the mortality and costs associated with IMV, understanding changing trends may better inform quality improvement measures and resource allocation. For example, identifying divergent trends in disease-specific outcomes would warrant further study into practice-pattern variations across diagnoses. As such, we sought to investigate population-based trends for all non-surgical patients receiving IMV as well as trends in outcomes for COPD, heart failure (HF), and pneumonia, the three most common causes of ARF[10], using a representative, population-based sample of hospitalizations in the US.

Methods

Study Population & Outcomes

Our data source was the US Agency for Healthcare and Research Quality's Healthcare Cost and Utilization Project's Nationwide Inpatient Sample (NIS). The NIS is a 20% stratified probability sample of all non-federal US acute care hospitalization that contains de-identified clinical and resource utilization data extrapolated from records for 5-8 million hospital discharges per year.[15] In 1993 the NIS contained data from 17 states, increasing to 44 states by 2009.

We identified adult patients (age ≥ 18 years) who received IMV during an acute hospitalization via International Classification of Disease, Ninth Revision, Clinical

Modification (ICD9-CM) code 96.7x for IMV only excluding patients with surgical Diagnosis Related Group Codes (**Table E1**). Among 100 randomly selected patients with *ICD9-CM* code 96.7x from the Boston University Clinical Data Warehouse from January 1, 2010 to June 30, 2013 we confirmed that 99 patients received IMV via chart review. We also developed *ICD9-CM* coding algorithms for defining COPD, HF, and pneumonia cohorts (**Table E2, E3, and E4)**.

Utilizing methods validated by Stein et al[16] with specificity of 99% and positive predictive value (PPV) of 85%, we defined COPD exacerbations by a principal diagnosis of COPD (*ICD9-CM* codes 491, 492 or 496) or a principal diagnosis of ARF (*ICD9-CM* 518.81)[17] with a secondary diagnosis of COPD. Similarly, we modified methods published by Lindenauer et al[18] to define pneumonia with a principal diagnosis of pneumonia (*ICD9-CM* codes 480.x-488.x and 507.x), a principal diagnosis of ARF with a secondary diagnosis of pneumonia, or a principal diagnosis of sepsis (*ICD9-CM* 038.x, 995.91, 995.92, or 785.52) with a secondary diagnosis of pneumonia.

Given the absence of published algorithms, we validated a novel algorithm to identify patients requiring IMV for HF. Extrapolating from methods previously used to identify HF in administrative databases [17,19], we defined our HF cohort using a principal diagnosis of HF (*ICD9-CM* 428.x), a principal diagnosis of ARF with a secondary diagnosis of HF, or a principal diagnosis of myocardial infarction (*ICD9-CM* 410.x) with a secondary diagnosis of HF. Using the Boston Medical Center Clinical Data Warehouse, we identified 101 mechanically ventilated patients meeting our *ICD9-CM* criteria for HF and 96 patients receiving IMV for other indications. Compared to a gold standard of manual chart review, our strategy demonstrated a sensitivity of 99%, specificity of 86%, and PPV of 84% (c-statistic=0.92, **Figure E1**) to identify patients with HF as the principal etiology of acute respiratory failure. Details of our exclusion criteria for all 3 disease cohorts can be found in the online **Supplemental Methods Section**.

We assessed annual incidence of IMV, hospital mortality, and length of stay (LOS) among the overall IMV cohort and among the disease-specific cohorts. National estimates for IMV utilization and hospital mortality were derived using survey-weighted methods. We normalized rates of IMV per year to the US adult population based on yearly US census data estimates.[20]

Statistical Analysis

We compared differences in continuous variables using the Student's T, ANOVA, and Kruskal-Wallis tests as appropriate. Categorical variables were compared using Chi-Square tests and the Cochran-Armitage test. We performed multivariable logistic regression for hospital mortality for each disease-specific cohort adjusting for age, gender, ethnicity, payer status, and Elixhauser comorbidities[21,22] (Healthcare Cost and Utilization Project's Comorbidity Software, Version 3.7). We determined linear trends in IMV mortality over time using hospital discharge year as a continuous variable. We also described changes over time in mortality by calculating average annual percentage change (AAPC) using Joinpoint version 4.1 (Statistical Research and Applications Branch, National Cancer Institute, Bethesda, Maryland). All other statistical analyses were performed using SAS version 9.3.

All statistical tests were conducted with alpha = 0.05 except for tests with multiple pairwise comparisons where a Bonferroni correction was used.

As trends may have been non-linear over time, we performed a sensitivity analysis for trends in mortality using year as a categorical as opposed to a continuous variable. Furthermore, to assess the effect of using more stringent definitions of the HF cohort on hospital mortality as well as to eliminate confounding by changing outcomes for acute myocardial infarctions we conducted an additional sensitivity analysis using a narrower algorithm for HF restricted to only those patients with a principle diagnosis of HF which had a high PPV (88%) but lower c-statistic (0.62) (**Figure E1)**. Finally, to address the addition of more states to the NIS over time we performed the same multivariate modeling for hospital mortality for all cohorts from 1998-2009 but restricted the analysis to the 22 states that contributed to the NIS in 1998 (the first year for which we had state identifiers). All study procedures were approved by the Boston University Medical Center Institutional Review Board.

Results

Trends in IMV Utilization

We identified 8,309,344 survey-weighted (1,675,914 unweighted) non-surgical patients who received IMV from 1993-2009. Utilization of IMV increased from 178.8 cases per 100,000 US adults (341,164 cases) in 1993 to 310.9 per 100,000 (723,310 cases) in 2009 (AAPC=3.5%, p<0.0001). During the study period, COPD, HF, and pneumonia accounted for 33.5% of all non-surgical IMV cases. Use of IMV for pneumonia showed the greatest growth between 1993 and 2009, doubling from 30.5 to 62.1 cases per 100,000 US adults (AAPC=4.4%, p<0.0001). Utilization of IMV for COPD remained stable, increasing from 18.6 to 19.1 cases per 100,000 US adults (AAPC=0.03%, p=0.95). In contrast, use of IMV for HF decreased by 55% from 25.3 to 11.3 cases per 100,000 US adults (AAPC=−4.7%, p<0.0001) (**Figure 1)**.

Patient Characteristics—Table 1 demonstrates the demographic characteristics and rates of comorbidities for non-surgical patients receiving IMV for 3 representative years of our study (1993, 2001, and 2009). Over time, patients requiring IMV were significantly younger (65.2 years in 1993 to 61.6 years in 2009), more likely to have Medicaid insurance (10.1% in 1993 to 14.3% in 2009), and had changing racial/ethnic distribution (lower percentages of white patients). We also observed an increasing number of comorbidities, with the percentage of patients with >2 comorbid conditions increasing from 32.2% to 60.7% (p<0.0001).

Hospital Outcomes

Hospital Mortality—Overall mortality for patients receiving IMV decreased significantly from 43.5% in 1993 to 32.2% in 2009. However, mortality trends differed according to etiology of respiratory failure. (**Figure 2, Table 2**). Mortality for pneumonia requiring IMV (44.2% to 34.2%, adjusted OR per 5 years 0.89) and COPD requiring IMV (23.1% to 18.5%, adjusted OR 0.97) decreased during the study period. However, mortality for HF increased significantly from 1993 to 2009 (31.9% to 32.7%, adjusted OR 1.10). From 1993

to 2009, hospital mortality for patients with HF surpassed that for COPD and began to approach that for pneumonia.

Sensitivity Analysis—We performed a sensitivity analysis for hospital mortality modeling year as a categorical variable as opposed to a continuous variable. Comparing adjusted hospital mortality in 2009 to 1993 showed an adjusted OR=0.70 (95% CI 0.69-0.71) for all patients requiring IMV, an adjusted OR=0.87 (95% CI 0.80-0.94) for COPD, an adjusted OR=1.31 (95% CI 1.21-1.41) for HF, and an adjusted OR=0.71 (95% CI 0.67-0.74) for pneumonia. When we restricted our definition of respiratory failure due to HF to only those patients with a principal diagnosis of HF (higher PPV=88% but lower c-statistic=0.62), hospital mortality for the HF cohort increased from 25.8% in 1993 to 38.9% in 2009 with an adjusted OR per 5 year =1.26 (95% CI 1.23-1.29). When we limited our analysis to the 22 states present in the NIS from 1998-2009, mortality trends were unchanged: all IMV OR=0.86 (95% CI 0.86-0.87); COPD OR=0.97 (95% CI 0.94-0.99); HF OR=1.10 (95% CI 1.07-1.13); PNA OR=0.85 (95% CI 0.84-0.86).

Length of Stay—Figure 3 depicts the changes in median LOS for survivors from 1993 to 2009. For all survivors of IMV the median LOS was clinically unchanged from 9.2 days in 1993 to 9.4 days in 2009. However median LOS for COPD, HF, and pneumonia with IMV decreased over this time period [10.0 days to 7.7 days for COPD ($p<0.0001$), 7.9 days to 6.0 days for HF ($p<0.0001$), and 13.1 days to 11.9 days ($p<0.0001$) for pneumonia].

In contrast to stable-to-decreasing hospital LOS, the duration of IMV in survivors increased significantly from 1993 to 2009. The percentage of survivors of IMV intubated for 96 hours or more increased from 28.8% in 1993 to 41.4% in 2009 ($p<0.0001$). Among survivors, the pneumonia cohort had the largest proportion of patients receiving IMV for 96 hours or more (48.5% in 1993 increasing to 56.0% in 2009, $p<0.0001$) while patients with HF experienced a smaller change in the percentage of patients receiving IMV for 96 hours or more (16.2% in 1993 increasing to 19.7% in 2009, $p<0.0001$). The proportion of survivors receiving IMV for COPD for 96 hours or more did not change significantly over time.

For survivors of IMV, routine discharges home decreased from 52.6% in 1993 to 30.7% in 2009 ($p<0.0001$) with significant increases in discharges to skilled nursing facilities (SNF) and long term acute care facilities (LTAC) (33.4% to 55.2%, $p<0.0001$). All three disease-specific cohorts experienced significantly lower rates of routine discharges home over time (COPD 55.6% to 34.2%, HF 55.4% to 36.0%, and pneumonia 45.8% to 22.8%, all $p<0.0001$) as well as significant increases to SNF and LTAC facilities (COPD 25.0% to 46.0%, HF 27.4% to 46%, and pneumonia 38.5% to 62.9%, $p<0.0001$).

Discussion

We investigated trends in incidence and outcomes for non-surgical patients receiving IMV in the US from 1993-2009. Our study demonstrates a large increase in the incidence of IMV for hospitalized adults. Epidemiological trends in IMV differed substantially based upon the etiology of respiratory failure. Use of IMV for patients with pneumonia appeared to drive the increase in IMV utilization, whereas use of IMV for COPD remained relatively stable

and use of IMV for patients with HF substantially declined. Interestingly, while hospital mortality has improved for patients with pneumonia and COPD, patients receiving IMV for HF have not experienced similar mortality improvements. Our findings were robust to multiple sensitivity analyses.

Prior studies investigating population-based trends for IMV incidence in the US are sparse. The International Study on Mechanical Ventilation (ISMV) investigated trends in IMV and non-invasive ventilation (NIV) and identified an increase from 1998 to 2010 in the number of patients requiring ventilatory support [1,2,9] Carson et al also found an increase in IMV in North Carolina from 1996-2002.[23] Conversely, Stefan et al demonstrated stable rates of IMV for patients with a principal diagnosis code for ARF in the United States from 2001-2009. Our current study demonstrates a significant increase in IMV for non-surgical patients in the US, a finding similar to the ISMV. Although drivers of the increase in utilization of IMV are unclear, we identified rising numbers of patients with multiple comorbidities over time which may predispose to increased severity of critical illness and need for IMV. Additionally, we found that pneumonia accounted for a large portion of the increase in IMV. While the etiology for the increase in IMV for pneumonia is unclear, increasing number of comorbidities as well as an aging US population may have increased the number of individuals with pneumonia and resulted in higher numbers requiring IMV.

Despite increased comorbidities, we identified declining hospital mortality rates among non-surgical patients requiring IMV, a finding consistent with reports from the ISMV and Carson et al.[9,23] Possible explanations for the decrease in overall IMV mortality include trends towards greater use of potentially lung protective ventilation strategies,[9]as well as improvements to processes of care for IMV patients such as sedation interruption[24-26], ventilator associated pneumonia prevention strategies[27,28], and ICU bundles. Unfortunately, we were unable to assess for changes in these processes of care using the NIS. However, improvements in mortality among patients receiving IMV may be overestimated, as patients receiving IMV were transferred earlier and more often to long-term care facilities over time. Because deaths occurring at long term care facilities soon after acute hospital discharge were not captured, further studies investigating mortality at 30 days or 1-year time points are warranted.

The evolution in the epidemiology of IMV during critical illness represents a growing financial burden to the healthcare system. In 2005, IMV contributed 12% of direct hospital costs and $27 billion annually in health care expenditures.[8] Our study demonstrates an ongoing trend towards increasing utilization of IMV, which suggests that costs related to IMV are likely to encompass a growing portion of healthcare expenditures. In addition, changes in the primary payer for IMV hospitalizations from Medicare to Medicaid indicate a shift in the source of reimbursement for IMV hospitalizations, a trend likely to continue with expansion of Medicaid under the Affordable Care Act. Furthermore, shorter acute care hospitalizations coupled with an increasing number discharges to long-term care hospitals may shift health care costs from acute care hospitals to long-term facilities, but may not lower health care expenditures.[29,30] Further investigations are needed to adequately analyze the impact of these trends on total healthcare costs and quality.

Several studies have investigated disease-specific IMV trends for COPD[12-14] with similar results to our findings of decreasing mortality associated with COPD. Chandra et al found decreases in initial use of IMV among patients hospitalized with COPD exacerbation. Our findings of increasing utilization of IMV for COPD are not necessarily inconsistent with Chandra et al's findings; we report use of IMV for COPD exacerbation among the US population, rather than among COPD hospitalizations. Our results highlight significant implications for healthcare resource allocation and costs associated with rising COPD incidence in the US[31].

We are unaware of prior studies comparing or reporting outcome trends among common indications for IMV such as HF or pneumonia. The differing trends in IMV utilization and adjusted hospital mortality for HF compared to COPD and pneumonia may have multiple explanations. One possibility is that the patient case-mix and severity of disease at the time of presentation changed differentially between the 3 disease cohorts leading to differing mortality trends. Unfortunately, the NIS does not contain traditional markers of severity of illness, but this area ought to be investigated in future studies. The rise in use of NIV for HF[32] may partially explain the decreased use of IMV for HF, but it is unclear why a similar trend was not observed for COPD, which has seen a similarly rapid rise in NIV utilization.[12,13,33] Increased use of NIV may have selected for progressively sicker patients with HF placed on IMV over time, although similar trends would also be expected with COPD. Another possible explanation for differences in hospital mortality among IMV patients with HF may be that significant advancements in outpatient management of chronic HF decreased overall mortality and rates of hospitalizations,[34-37] and patients with HF who required IMV represented a progressively sicker population who had failed medical management of HF.

Our findings should be considered in light of several limitations. While we analyzed a large, nationally representative sample of hospitalized patients, we lacked granular data on physiologic parameters, ventilator settings, code status, and other factors that may affect mortality. Further studies should investigate whether changes in processes of care for IMV may be utilized differently based on diagnosis or provider specialty. Changes in *ICD9-CM* coding practices over time (i.e. the tendency to document the greatest number of *ICD9-CM* codes to increase reimbursement) are a limitation of all administrative claims data based research including our own study. Changing performance characteristics of *ICD9-CM* codes to identify clinical disease states over time may have contributed to changes in disease incidence and outcomes. In order to attenuate misclassification of disease, we either used well-validated algorithms to identify conditions using *ICD9-CM* codes, or developed and validated novel algorithms. In addition to coding practices, the NIS itself evolved over the study period with increasing number of states contributing to the database. However, our sensitivity analysis limited to states present in 1998 showed similar mortality trends to our primary analysis suggesting that regional changes to the NIS should have little impact on our conclusions.

In conclusion, our study helps to clarify knowledge gaps related to epidemiologic trends in IMV utilization in the United States. We identified large increases in the utilization of IMV as well as significant changes in hospital outcomes and discharge practices that have

implications for future healthcare resource allocation. We found disease-specific variation among patients receiving IMV, with the incidence and outcomes of patients with HF contrasting sharply with patients with COPD or pneumonia. As there have been few new treatments aimed specifically at acute respiratory failure for patients with COPD, HF, and pneumonia, further investigations are needed to identify differences in IMV-specific processes of care that could account for the outcome gaps. Defining areas of practice pattern variation may help identify targets for quality improvement interventions that can change the direction of mortality trends among HF patients compared to COPD and pneumonia patients.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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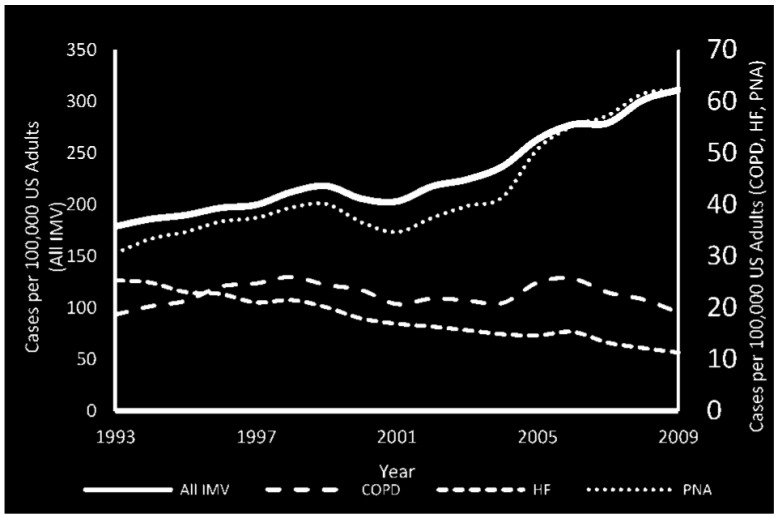

Figure 1.

Incidence of invasive mechanical ventilation in the United States: 1993-2009.

Abbreviations: IMV – Invasive mechanical ventilation, COPD – chronic obstructive pulmonary disease, HF- heart failure, PNA – pneumonia.

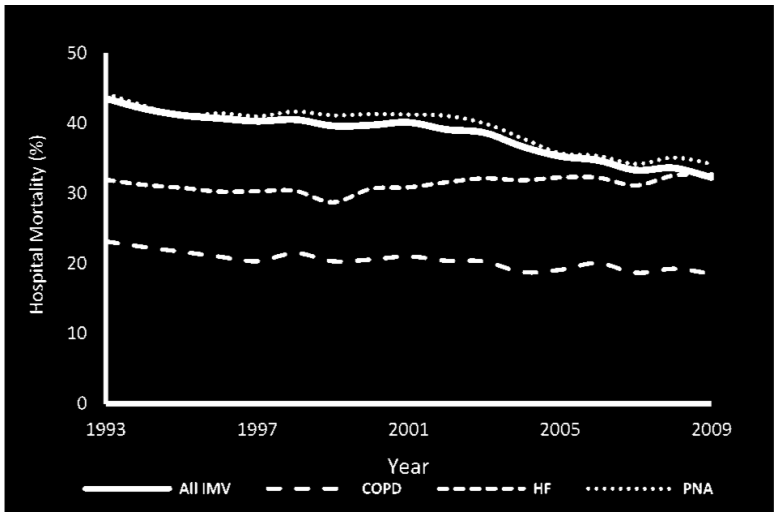

Figure 2.

Unadjusted hospital mortality for patients receiving invasive mechanical ventilation in the United States: 1993-2009. Abbreviations: IMV – Invasive mechanical ventilation, COPD – chronic obstructive pulmonary disease, HF- heart failure, PNA – pneumonia.

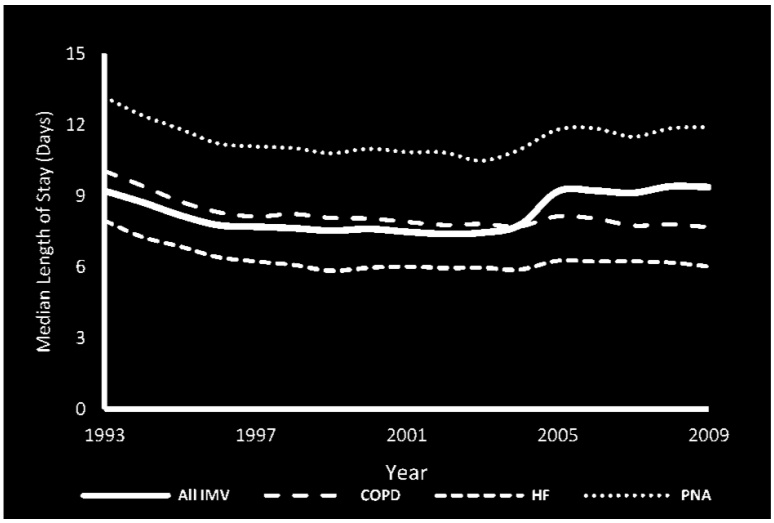

Figure 3.

Median hospital length of stay for patients receiving invasive mechanical ventilation in the United States: 1993-2009. Abbreviations: IMV – Invasive mechanical ventilation, COPD – chronic obstructive pulmonary disease, HF- heart failure, PNA – pneumonia.

Table 1

Baseline demographics and comorbidities for 3 representative years*

	1993 (n=341,164)	2001 (n=431,144)	2009 (n=723,310)	p-value**
Age: Mean (SD)	65.2 (17.4)	64.2 (17.7)	61.6 (17.7)	<0.0001
Male	51.4	50.9	53.2	<0.0001
Race				<0.0001
White	60.1	54.7	56.8	
Black	11.5	11.6	14.0	
Hispanic	5.5	6.4	7.9	
Other†	22.9	27.2	21.3	
Primary Payer				<0.0001
Medicare	61.5	58.4	54.4	
Medicaid	10.1	11.6	14.3	
Private Insurance	19.1	21.5	20.7	
Other†	9.4	8.5	10.6	
Comorbidities				<0.0001
No comorbidities	12.8	7.0	4.7	
1-2 comorbidities	55.1	44.2	34.6	
>2 comorbidities	32.2	48.9	60.7	
Chronic HF	27.7	27.3	22.3	<0.0001
Chronic Lung Disease	26.7	31.7	28.4	<0.0001
Valvular Heart Disease	7.1	7.8	4.0	<0.0001
Peripheral Vascular Disease	3.1	4.1	5.0	<0.0001
Hypertension	20.5	34.4	42.6	<0.0001
Paralysis	3.2	4.4	6.3	<0.0001
Other Neurologic Disorders	9.2	12.3	12.8	<0.0001
Diabetes w/o chronic complications	10.6	17.1	20.1	<0.0001
Renal Failure	4.2	8.2	15.5	<0.0001
Liver Disease	2.3	4.1	4.2	<0.0001
Metastatic Cancer	2.7	3.3	3.2	<0.0001
Obesity	1.5	3.4	7.4	<0.0001
Weight Loss	3.9	6.5	15.3	<0.0001
Alcohol Abuse	6.1	8.5	8.8	<0.0001
Drug Abuse	2.6	4.5	5.7	<0.0001

*We chose the first year (1993), the middle year (2001), and final year of our study (2008) to convey representative temporal changes in patient characteristics.

**All statistical testes represent trends over the 17 year study sample.

†Includes individuals for whom data was missing.

Table 2

Association between year of hospitalization and hospital mortality for patients on IMV

Etiology of respiratory failure	Odds Ratio per 5 years (95% CI)		Hospital Mortality AAPC (%) (95% CI)
	Unadjusted	Multivariable Adjusted*	
All IMV	0.87 (0.87, 0.87)	0.90 (0.89, 0.90)	−1.7 (−2.0, −1.4)
COPD	0.93 (0.92, 0.94)	0.97 (0.97, 0.98)	−1.1 (−1.4, −0.8)
Heart Failure	1.02 (1.01, 1.04)	1.10 (1.09, 1.12)	0.3 (0.0, 0.6)
Pneumonia	0.88 (0.87, 0.88)	0.89 (0.88, 0.90)	−1.6 (−1.9, −1.2)

Abbreviations: CI: confidence interval, AAPC: average annual percentage change. IMV: invasive mechanical ventilation. COPD: chronic obstructive pulmonary disease.

*Adjusted for age, gender, ethnicity, payer status, and Elixhauser comorbidities