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# Impact of the Fall 2009 Influenza A(H1N1)pdm09 Pandemic on US Hospitals

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**Background:** Understanding how hospitals functioned during the 2009 influenza A(H1N1)pdm09 pandemic may improve future public health emergency response, but information about its impact on US hospitals remains largely unknown.

**Research Design:** We matched hospital and emergency department (ED) discharge data from the Agency for Healthcare Research and Quality (AHRQ) Healthcare Cost and Utilization Project with community-level influenza-like illness activity during each hospital's pandemic period in fall 2009 compared with a corresponding calendar baseline period. We compared inpatient mortality for sentinel conditions at high-surge versus nonsurge hospitals.

**Results:** US hospitals experienced a doubling of pneumonia and influenza ED visits during fall 2009 compared with prior years, along with an 18% increase in overall ED visits. Although no significant increase in total inpatient admissions occurred overall, approximately 10% of all study hospitals experienced high surge, associated with higher acute myocardial infarction and stroke case fatality rates. These hospitals had similar characteristics to other US

hospitals except that they had higher mortality for acute cardiac illnesses before the pandemic. After adjusting for 2008 case fatality rates, the association between high-surge hospitals and increased mortality for acute myocardial infarction and stroke patients persisted.

**Conclusions:** The fall 2009 pandemic period substantially impacted US hospitals, mostly through increased ED visits. For a small proportion of hospitals that experienced a high surge in inpatient admissions, increased mortality from selected clinical conditions was associated with both prepandemic outcomes and surge, highlighting the linkage between daily hospital operations and disaster preparedness.

**Key Words:** pandemic influenza, hospital surge capacity, emergency department

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In the decade preceding the influenza A(H1N1)pdm09 pandemic, governments worldwide engaged in extensive pandemic planning.<sup>1,2</sup> Between April 2009 and April 2010, an estimated 60.8 million Americans became ill, 274,000 were hospitalized, and 12,500 died due to pH1N1.<sup>3</sup> Postpandemic review confirmed that visits to specialized, pediatric emergency departments (EDs) increased dramatically.<sup>4</sup> Despite some media reports of overwhelmed EDs and inpatient settings in the United States,<sup>5</sup> no nationwide analyses of the impact of the pH1N1 pandemic on acute care hospitals or EDs are available.

We linked the Healthcare Cost and Utilization Project (HCUP), a nationwide, administrative data source that captures hospital admissions and ED encounters,<sup>6</sup> with the US Centers for Disease Control and Prevention's (CDC) Influenza-Like Illness Surveillance Program (ILINet) data, to assess the impact of the 2009 pH1N1 fall wave on US hospitals and EDs.<sup>3,7,8</sup>

## METHODS

### General Approach

To measure pH1N1 surge and its impacts, we conducted 3 types of analyses. First, we compared the volume of

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ED visits and inpatient admissions during the pH1N1 fall wave with previous years as baseline. Second, we compared ED and inpatient admission volume between the pH1N1 fall wave and the 2003–2004 influenza season, the most severe season in the last decade.<sup>9</sup> Third, we compared in-hospital mortality for selected conditions in high-surge, medium-surge, and nonsurge hospitals during the pH1N1 fall wave. Table 1 provides an overview of data sources and methods.

## Data Sources

Patient-encounter data came from HCUP State Inpatient Databases (SID) and State Emergency Department Databases (SEDD).<sup>6</sup> HCUP contains patient age, sex, primary expected payer, severity of illness, length of stay (inpatient only), and discharge disposition.<sup>10</sup> We identified patient comorbidities using the Elixhauser Comorbidity Software.<sup>11</sup> We included data from 2387 and 1832 acute care hospitals and EDs, respectively, in 26 SIDs and 19 SEDDs (Supplemental Digital Content 1, <http://links.lww.com/MLR/A418> for map of included states). We analyzed ED treat-and-release visits, all ED visits, and inpatient admissions, as well as inpatient census:bed ratio. We considered the following patient subcategories: pregnancy and elective admissions

with a procedure performed<sup>12</sup> (Supplemental Digital Content 1, <http://links.lww.com/MLR/A418> for detailed definitions).

Hospital size, ownership, and teaching status were derived from the American Hospital Association's (AHA) 2008 Annual Survey.<sup>13</sup>

Influenza cases were generally uncommon during the fall seasons of baseline years, except 2003. To provide a meaningful comparison between periods; therefore, we based our main analyses on total encounters and pneumonia and influenza (P&I) encounters (Supplemental Digital Content 2, <http://links.lww.com/MLR/A419> for influenza-only analysis).

## Study Periods

For our primary analyses, we used ILINet to identify hospital-specific pandemic periods<sup>8</sup> during fall 2009, defined as weeks in which influenza-like illness activity in a hospital's Core Based Statistical Area<sup>14</sup> was >3 SDs above baseline.<sup>3,15–17</sup> We restricted each hospital's data to its Core Based Statistical Area-specific pandemic time period.

Not all hospitals, especially those in rural locations, could be included in this primary analysis since the ILINet surveillance did not encompass all geographic regions. Therefore, we performed a sensitivity analysis using all

**TABLE 1.** Description of Overall Approach, Data, and Statistical Methods Used in Analyses of Hospital and ED Impacts Associated With the pH1N1 Fall Wave in the United States

Outcomes	Pandemic Period	Comparison Period	Statistical Analysis
<i>Analysis 1: Surge in the pH1N1 pandemic period compared with prior baseline years</i>			
No. inpatient admissions*	pH1N1 pandemic weeks in fall 2009, defined at the CBSA level based on CDC's ILINet surveillance. Sensitivity analysis using a fixed pandemic period (August 30–December 12, 2009)	Corresponding weeks in 2003–2008	% change in number of encounters in 2009 vs. baseline, <i>t</i> test
No. ED encounters (all and treat-and-release only)*	pH1N1 pandemic weeks in fall 2009, defined at the CBSA level based on CDC's ILINet surveillance. Sensitivity analysis using a fixed pandemic period (August 30–December 12, 2009)	Corresponding weeks in 2005–2008	% change in number of encounters in 2009 vs. baseline, <i>t</i> test
Census:bed ratio*	pH1N1 pandemic weeks in fall 2009, defined at the CBSA level based on CDC's ILINet surveillance	Corresponding weeks in 2003–2008	% hospitals in 2009 with a >20% increase in census:bed ratio over baseline period
<i>Analysis 2: Surge in the pH1N1 pandemic period compared with severe 2003–04 influenza season</i>			
No. inpatient admissions <sup>†</sup>	August 30–December 12, 2009	November 2, 2003–January 10, 2004	% change in number of encounters and encounters per day in 2009 vs. 2003–04
No. ED encounters (all and treat-and-release only) <sup>†</sup>	August 30–December 12, 2009	November 2, 2003–January 10, 2004	% change in number of encounters and encounters per day in 2009 vs. 2003–04
<i>Analysis 3: Association of in-hospital mortality with high surge</i>			
In-hospital mortality for AMI, CHF, stroke, injury (adults), and injury, and chronic conditions (pediatrics)	pH1N1 pandemic weeks in fall 2009, defined at the CBSA level based on CDC's ILINet surveillance. Sensitivity analysis using (1) ED surge; (2) additional hospital and local area control variables; and (3) a fixed pandemic period (August 30–December 12, 2009)	—	Logistic regression with controls for patient and hospital characteristics, including 2008 in-hospital mortality rate for condition

\*If a facility did not report SID or SEDD data during a baseline year, we imputed the missing data using average values from the available baseline years. We required the baseline comparison periods to have no more than approximately 10% of imputed data.

<sup>†</sup>Restricted to hospitals providing SID and SEDD data in 2003, 2004 and 2009.

AMI indicates acute myocardial infarction; CBSA, Core Based Statistical Area; CDC, Centers for Disease Control and Prevention; CHF, congestive heart failure; ED, emergency department; SEDD, State Emergency Department Databases; SID, State Inpatient Databases.

hospitals based on a uniform pandemic time period—August 30 to December 12, 2009—the first and last weeks when national influenza-like illness prevalence was >3 SDs above baseline.<sup>15</sup>

## Analyses

### ED and Inpatient Volume

To measure the extent of inpatient surge during the pH1N1 fall wave, we calculated the difference between admissions during the pandemic period and mean admissions during corresponding weeks in prior years separately for each hospital. We then divided the difference by the SD of the baseline number of admissions (Z-score). We categorized hospitals based on the Z-score as follows: “high-surge hospitals” (Z-score  $\geq 2$ ), “medium-surge hospitals” ( $0 < \text{Z-score} < 2$ ), and “no-surge hospitals” (Z-score  $\leq 0$ ). We repeated these analyses with uniform pandemic periods and used an analogous approach with ED data.

Next, we calculated the hospital-specific weekly census:bed ratio to account for patients admitted to the facility and patients who were still in the facility during pandemic weeks (ie, the number of patients who were present in the hospital during an outbreak week divided by the number of “set up and staffed” hospital beds). We compared the 2009 pandemic census:bed ratio to the hospital-specific baseline average for corresponding weeks in previous years.

We also compared ED visits and inpatient admissions during the pH1N1 fall wave with those during the severe 2003–2004 influenza season. Given the different length of influenza activity periods in this analysis, we compared average daily volumes and cumulative volumes.

### Mortality Risk Analyses

To assess whether increased patient volume during the pH1N1 fall wave impacted hospitals’ capabilities to deliver quality health care, we analyzed the mortality risk for patients with conditions commonly used to assess hospitals’ processes of care: adults with acute myocardial infarction (AMI), congestive heart failure (CHF), stroke, traumatic injury, and pediatric patients with traumatic injury or chronic

comorbidities. For each condition, we assessed the association of in-hospital mortality with surge (high, medium, and no surge) during the pH1N1 fall wave. We analyzed encounter-level data with multivariable logistic regression models controlling for patient sex, age, comorbidities, P&I diagnosis, severity of illness, hospital bed size, teaching status, and ownership. To control for baseline quality of care, we included the 2008 hospital-specific mortality rate for the studied clinical condition as a covariate. We used 2008 rather than the whole range of 2003–2008 to establish the baseline mortality for the regression analyses to avoid confounding with secular trends in improved care for these conditions from 2003 to 2007. We used logistic regression with SEs adjusted for the clustering of admissions in hospitals (Supplemental Digital Content 1, <http://links.lww.com/MLR/A418> for variable definitions and Supplemental Digital Content 2 for sensitivity analyses).

## RESULTS

### Encounter Volume in Pandemic and Comparison Periods

We obtained hospital-specific pandemic period information for 1047 (43.9%) SID hospitals and 760 (41.5%) SEDD hospitals. Pandemic activity lasted a median of 8 weeks for each hospital.

Using the hospital-specific pandemic period, EDs had 4,468,880 total visits and 3,756,251 treat-and-release encounters during 2009 pandemic weeks, an approximately 18% increase over baseline ( $P < 0.05$ , Table 2 and Supplemental Digital Content 2, <http://links.lww.com/MLR/A419>). More than 88% of EDs experienced an increase in visits. Sensitivity analyses using the uniform pandemic period demonstrated smaller percentage increases (Table 2).

In comparison with 2003–2004 seasonal influenza, total ED encounters and treat-and-release ED encounters per day were 31% and 34% higher, respectively, during the pH1N1 fall wave. Much of the increase was due to visits with diagnostic codes for conditions other than P&I (Table 3).

**TABLE 2.** Change in Hospital Volume During pH1N1 Fall Wave Compared With Baseline Years,\* by Disease Category and Type of Encounter

Disease Category†	Hospital-specific Pandemic Period			Uniform Pandemic Period		
	2005–2008 Annual Mean	2009	% Change in 2009 (P)	2005–2008 Annual Mean	2009	% Change in 2009 (P)
Emergency departments, all encounters						
All encounters	3,795,393	4,468,880	17.7 % ( $P = 0.001$ )	9,154,938	10,517,302	14.9% ( $P < 0.001$ )
Pneumonia and influenza	90,090	270,272	200.0% ( $P < 0.001$ )	223,782	530,982	137.3% ( $P < 0.001$ )
Emergency departments, treat-and-release encounters						
All encounters	3,162,509	3,756,251	18.8% ( $P < 0.001$ )	7,719,656	8,837,940	14.5% ( $P < 0.001$ )
Pneumonia and influenza	30,023	184,482	514.5% ( $P < 0.001$ )	75,039	330,051	339.8% ( $P < 0.001$ )
Inpatient admissions						
All encounters	1,994,227	2,002,614	0.4% ( $P = 0.44$ )	4,533,741	4,549,623	0.4% ( $P = 0.54$ )
Pneumonia and influenza	104,309	147,616	41.5% ( $P < 0.001$ )	251,498	338,062	34.4% ( $P < 0.001$ )

\*Baseline years for the inpatient analysis are 2003–2008. For the emergency department analysis, baseline years are 2005–2008.

†Sensitivity analysis based on influenza-specific codes presented in Supplemental Digital Content.

**TABLE 3. Hospital Volume During pH1N1 Fall Wave Compared With 2003–2004 Seasonal Influenza Epidemic, by Disease Category and Type of Encounter**

Disease Category*	2003–2004			Fall 2009		
	No. Encounters	Encounters Per Day	% Change From 2003 to 2004	No. Encounters	Encounters Per Day	% Change From 2003 to 2004
Emergency departments, all encounters†						
All encounters	1,867,861	26,684	96.38%	3,668,021	34,934	30.92%
Pneumonia and influenza	125,279	1,790	59.02%	199,216	1,897	5.98%
Emergency departments, treat-and-release encounters‡						
All encounters	1,537,290	21,961	101.56%	3,098,494	29,510	34.37%
Pneumonia and influenza	74,385	1,063	75.87%	130,824	1,246	17.22%
Inpatient admissions‡						
All encounters	3,099,931	44,285	46.68%	4,546,920	43,304	–2.22%
Pneumonia and influenza	288,956	4,128	16.90%	337,791	3,217	–22.07%

\*Sensitivity analysis based on influenza-specific codes presented in Supplemental Digital Content.

†The emergency department analysis was performed using data from the following states, which were available in both time periods: Georgia, Hawaii, Indiana, Maryland, Missouri, Minnesota, Nebraska, South Carolina, Tennessee, and Vermont.

‡The inpatient analysis was performed using data from the following states, which were available in both time periods: Arizona, California, Colorado, Georgia, Hawaii, Illinois, Indiana, Iowa, Kentucky, Maryland, Missouri, Minnesota, Nebraska, Nevada, New Jersey, Ohio, Oregon, Rhode Island, South Carolina, South Dakota, Tennessee, Virginia, Vermont, Washington, and Wisconsin.

**TABLE 4. Comparison of High Surge to All Other Hospitals**

Characteristics	High-surge Hospitals	All Other Hospitals (n = 106)	P* (n = 941)
Teaching status (%)			
Teaching	37.74%	33.91%	0.43
Nonteaching	62.26%	66.09%	
Ownership (%)			
Public	11.32%	11.77%	0.30
Nonprofit ownership	77.26%	71.17%	
For-profit ownership	11.32%	17.06%	
Location (%)			
Urban	98.11%	93.74%	0.11
Rural	1.89%	6.26%	
Average No. set up and staffed beds	280.3	249.1	0.10

\* $\chi^2$  or *t* test.

Total hospitals admission volume was similar during pandemic and baseline weeks (statistically insignificant 0.4% increase during pandemic weeks, Table 2). Although fewer than half of hospitals had any increase in admissions, about 8% had more than a 20% increase in admissions over baseline; 10% of hospitals had greater than a 20% increase in census:bed ratio.

Our sample included 106 high-surge hospitals (10%), 386 moderate-surge hospitals (37%), and 555 hospitals (53%) that had no surge in admissions. High-surge hospitals were of similar size, ownership, urban/rural location, and teaching status as the other hospitals (Table 4).

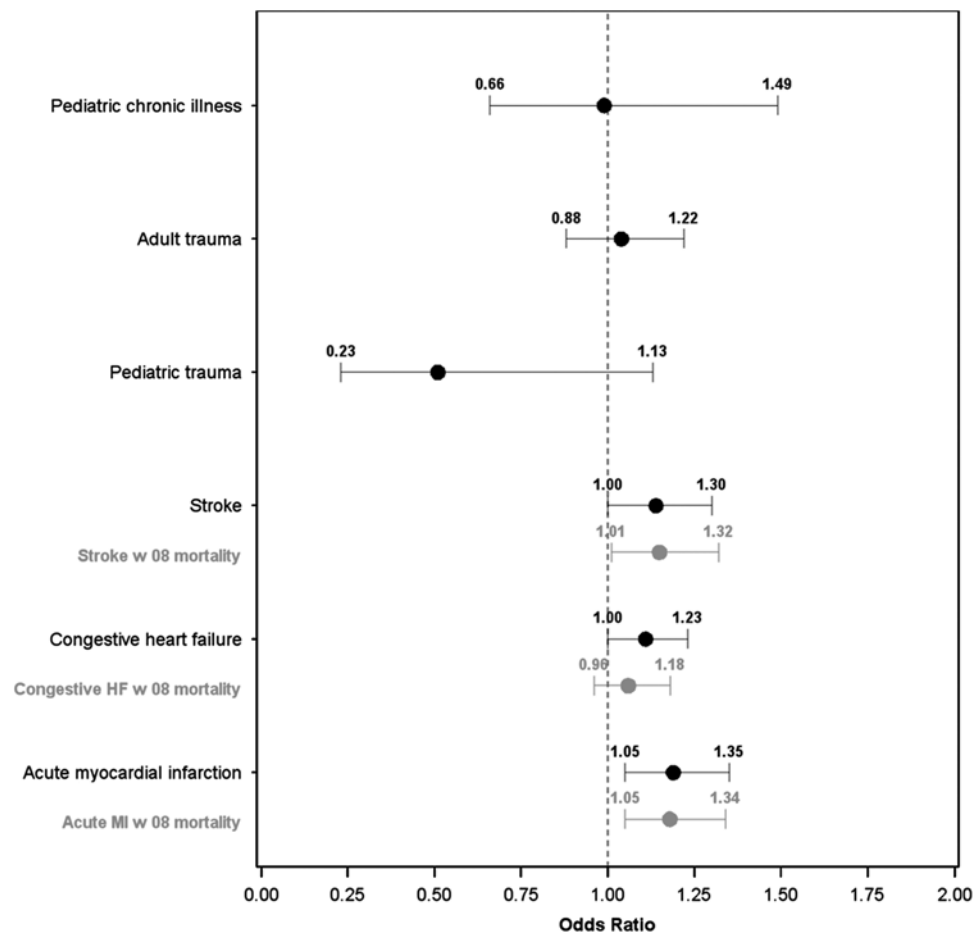
In contrast to all-cause admissions, there was widespread surge in P&I admissions associated with the pH1N1 fall wave, with >87% of hospitals experiencing an increase over baseline. Yet when the pH1N1 fall wave was compared with the 2003–2004 influenza season, daily P&I admissions were decreased by 22% (Table 2).

In fall 2009, hospital admissions for births and other delivery-related conditions declined by 5.5% compared with previous years, making it the clinical category responsible for the largest reduction of admissions. We did not find a consistent pattern of decreases in elective admissions for procedures (data not shown).

## In-hospital Mortality and Surge

Patients with stroke, CHF, or AMI at a high-surge hospital had a significant increase in mortality risk compared with patients with those conditions at no-surge hospitals (Fig. 1). There was no association between hospital surge level and mortality risk for adult or pediatric trauma or for pediatric patients with chronic conditions.

CHF and AMI patients admitted to hospitals in 2008 that experienced high surge in 2009 had statistically significant higher mortality risk (data not shown). Yet after adjusting for 2008 mortality rates, an elevated mortality risk remained at hospitals experiencing high surge in 2009 pandemic weeks for patients with AMI and stroke (Fig. 1). Sensitivity analyses using the uniform pandemic period gave similar results.



**FIGURE 1.** Adjusted odds ratios for mortality by condition, high-surge hospitals versus nonsurge hospitals during the pH1N1 fall wave. Covariates (not shown on figures) include age, sex, All Patient Refined Diagnosis Related Group (APR-DRG) severity, presence of 29 Comorbidity Software variables, hospital size, hospital teaching status, hospital ownership/control, as well as pneumonia and influenza diagnosis.

We found no significant association between ED surge and in-hospital mortality, and these findings were not sensitive to alternative definitions of ED surge based on different Z-score cutpoints.

## DISCUSSION

During the pH1N1 fall wave, we found large increases in ED visits over baseline, but only a subset of hospitals experienced high inpatient surge. We found evidence that hospitals with poorer prepandemic outcomes may have even poorer outcomes during times of surge.

The combination of unchanged total hospital admissions and increased P&I admissions over baseline during the pH1N1 fall wave suggests an offsetting decrease in admissions for other conditions. Although pregnant woman made up a disproportionate share of patients admitted for influenza complications<sup>18,19</sup> during the pandemic, hospitals experienced a relatively sharp decline in the total number of labor-related and delivery-related admissions. The reduction in

births was a likely consequence of the concurrent US economic slowdown<sup>20</sup> and may have offset one third of the increase in admissions due to P&I.

In contrast to inpatient volumes, high surge in EDs was not associated with increased mortality risk for inpatients with the conditions considered. A number of factors, including changes in staffing and operations, likely contributed to the ability of EDs to surge. These efforts merit additional investigation as they could provide valuable lessons for the future.

The SID and SEDD used in this study cover a subset of states. Nevertheless, the states in our analyses still represent 54% and 41% of the US population, respectively. HCUP provides the most comprehensive data available on hospital and ED use at the encounter level. When combined with ILINet, HCUP's broad geographic representation and inclusivity of all ages and payers allowed a more detailed analysis of health care utilization than would have been possible using administrative data from Medicare or individual health plans.

Our study is subject to important limitations. The associations among influenza activity, cardiovascular events, and mortality have been frequently described.<sup>21</sup> Also, respiratory infections have been associated with stroke incidence and stroke severity.<sup>22</sup> Our mortality risk analysis could have been confounded if high-surge hospitals were associated with higher influenza activity than nonsurge hospitals and if mortality risk was higher in AMI patients with influenza than in AMI patients without influenza. However, we did not find evidence for such an interaction after adjustment for age, comorbidities, and severity of illness.

A further limitation may have been our definition of epidemic activity, although we considered both local and nationally representative pandemic periods. Alternative measures may have identified less extreme but more temporally durable excursion over the normal range. In addition, outbreaks in a given community may not immediately be reflected in the geographically proximate hospitals.

The finding that hospital-specific pandemic surge and mortality risk for selected conditions were associated with prepandemic quality of care provides an intriguing insight regarding the relationship between some specific measures of hospital quality and emergency-specific hospital preparedness. We cannot determine whether this increase in baseline mortality is due to patient mix, hospital care processes, or even residual confounding due to imbalanced effects of influenza on certain hospitals.<sup>23</sup> Despite these limitations, the finding offers a unique opportunity to consider the broader linkages between daily hospital operations and disaster preparedness. Structural and procedural efforts to increase some aspects of hospital quality have the potential to induce positive effects on acute and longer-term hospital emergency response capabilities. Improving baseline quality and providing additional support during surges may improve performance in hospitals with underlying quality issues. Support may include directing patients with selected conditions away from high-surge hospitals. However, more research is needed to fully elucidate the association between hospital quality and performances in emergency situations and assess how to best support hospitals during such events, before firm recommendations can be made.

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