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RESEARCH ARTICLE

Impact of State Reporting Laws on Central Line–Associated Bloodstream Infection Rates in U.S. Adult Intensive Care Units

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Objective. To examine the effect of mandated state health care–associated infection (HAI) reporting laws on central line–associated bloodstream infection (CLABSI) rates in adult intensive care units (ICUs).

Data Sources. We analyzed 2006–2012 adult ICU CLABSI and hospital annual survey data from the National Healthcare Safety Network. The final analytic sample included 244 hospitals, 947 hospital years, 475 ICUs, 1,902 ICU years, and 16,996 ICU months.

Study Design. We used a quasi-experimental study design to identify the effect of state mandatory reporting laws. Several secondary models were conducted to explore potential explanations for the plausible effects of HAI laws.

Principal Findings. Controlling for the overall time trend, ICUs in states with laws had lower CLABSI rates beginning approximately 6 months prior to the law's effective date (incidence rate ratio = 0.66; $p < .001$); this effect persisted for more than 6 1/2 years after the law's effective date. These findings were robust in secondary models and are likely to be attributed to changes in central line usage and/or resources dedicated to infection control.

Conclusions. Our results provide valuable evidence that state reporting requirements for HAIs improved care. Additional studies are needed to further explore why and how mandatory HAI reporting laws decreased CLABSI rates.

Key Words. Public reporting, quality, health care-associated infections, hospitals, CLABSI

Despite ongoing advances in medical technology and health care, health care–associated infections (HAI) continue to represent common adverse events for hospitalized patients; at any given time, an estimated 1 in 20 hospitalized patients has an HAI, leading to significant morbidity, mortality, and cost (Klevens et al. 2007; Scott 2009). In the landmark publication "To Err Is Human" (Institute of Medicine 2000), authors argued for external pressures to incentivize health care organizations and providers to take action to improve safety. Recently, many states have enacted HAI reporting laws to improve safety and quality of care (Reagan and Hacker 2012; Herzig et al. 2015). Key reporting requirements in the HAI laws vary across states, including (1) mandatory data submission either to a state agency or the National Healthcare Safety Network (NHSN), (2) public reporting, and (3) public disclosure of facility identifiers (Reagan and Hacker 2012). Moreover, federal regulations have ensued, including nonpayment by the Centers for Medicare and Medicaid Services (CMS) for certain HAIs (Centers for Medicare and Medicaid Services 2015a), and the inclusion of HAI rates in the Value Based Purchasing program of the Affordable Care Act in 2010 (Centers for Medicare and Medicaid Services 2014).

During the last decade, using data from the NHSN of the Centers for Disease Control and Prevention (CDC), researchers have found that rates of HAIs such as central line–associated bloodstream infections (CLABSIs) have decreased substantially (Centers for Disease Control and Prevention 2014). Whether this decrease was driven by federal incentives, other national trends and/or state reporting requirements remains unclear (Lee et al. 2012; Kawai et al. 2015).

A number of researchers have attempted to evaluate the impact of state reporting of CLABSIs with mixed results (Kim and Black 2011; Stone et al. 2011; Pakyz and Edmond 2013; Marsteller, Hsu, and Weeks 2014; Flett et al. 2015; Rinke et al. 2015). Pakyz et al. used 2011 data from 159 academic hospitals and did not detect an effect of state mandatory reporting on CLABSI rates, but their analysis was cross-sectional and the sample was small (Pakyz and Edmond 2013). Kim and Black (2011) found that after reporting started in

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2004, CLABSI rates based on inpatient discharge data in Pennsylvania declined 14 percent compared with 9 percent in control states during 2004–2008. Stone et al. (2011) conducted surveys of hospitals in California during a 1.5-year period, before and after mandatory public reporting, and found a significant reduction in CLABSI rates. Among hospitals participating in a national patient safety collaborative implemented in 2009–2011, those located in states with public reporting laws had a larger decline in CLABSI rates during only the first 6 months of the collaborative (Marsteller, Hsu, and Weeks 2014). Leveraging the 2000–2009 Kids' Inpatient Database, Rinke et al. (2015) examined changes in pediatric CLABSI rates by comparing never-reporting states to those with reporting starting in 2006 or starting in 2009; the results showed that never-reporting states had comparable or even larger rate declines. And, in a recent study, researchers found that mandatory public reporting of CLABSIs was not associated with the utilization of blood culture or antibiotics among pediatric and neonatal ICUs at 17 children's hospitals (Flett et al. 2015).

To further inform policy makers, we examined the relationship between state HAI reporting laws and CLABSI rates over a 6 1/2-year time period using a large, national sample of hospitals and ICUs reporting infection data to the NHSN between 2006 and 2012. The NHSN CLABSI definition is a laboratory-confirmed bloodstream infection in a patient who had a central line within 48 hours prior to the development of the infection and that is not related to an infection at another site. We chose the NHSN CLABSI definition (as opposed to other metrics, such as administrative coding) because of the long-established application and acceptance among infection prevention and health care epidemiology experts (Talbot et al. 2013). We aimed to assess the incremental effect of state mandatory reporting laws above and beyond the impact of federally mandated laws by utilizing longitudinal data for states that passed state-specific HAI reporting laws and those that did not.

Conceptual Framework

In theory, public reporting of provider performance is expected to drive improvement in the quality of care, and prior studies have found several causal pathways between quality reporting and quality improvement. As proposed by Berwick, James, and Coye (2003), the first pathway is through consumer or purchaser selection that would drive market share and therefore weed out low performers (the selection pathway). The second pathway is through the change of providers when informed of their quality deficits (the change pathway). A third causal pathway, proposed by Hibbard, Stockard, and Tusler (2003), is that providers are driven to improve their performance because they are concerned about their reputation once the quality information is made public (the reputation pathway). The authors showed that public reporting through the reputation pathway generated a significantly larger improvement in provider performance than private confidential reporting through the change pathway.

Prior empirical studies provide some support for the impacts of public reporting on provider performance. For example, public reporting of cesarean section rates was associated with changes in hospital practice patterns (Caron and Neuhauser 1999; Jang et al. 2011). Smith et al. (2012) found that providers' adoption of diabetes management improvement interventions was associated with public reporting of diabetes care performance. A recent systematic review suggests that public reporting is associated with small declines in inpatient mortality and improvements as measured by Consumer Assessment of Healthcare Providers and Systems, and Healthcare Effectiveness Data and Information Set (Totten et al. 2012). Nonetheless, some studies fail to find impacts of public reporting (Ryan, Nallamothu, and Dimick 2012). The effects of public reporting as demonstrated in the prior literature, however, are mostly attributed to the change and reputation pathways, with little or no effect through the selection pathway (Contandriopoulos, Champagne, and Denis 2014).

The implication of the public reporting literature is that we would expect state mandatory HAI reporting laws to impact hospital CLABSI rates mainly through the change and reputation pathways. Hospitals may change their practices and improve performance at several stages. In anticipation of the submission and reporting of infection data, and because of potential penalties associated with high infection rates such as damages to reputation and/or business, some hospitals may start to change their practice prior to the enactment of a reporting law (e.g., during the phase of public debate). For instance, prior to mandatory public reporting of infection rates in California, over 70 percent of hospitals had fully implemented evidence-based guidelines; rural hospitals were less likely to adopt guidelines (Halpin et al. 2011). A second wave of adopting practice changes may occur after public reporting implementation when hospitals realize that their rates are higher than their peers, as suggested by increased adoption of proven interventions to reduce CLABSI rates by hospitals in states with mandatory reporting requirements in comparison to those in nonreporting states (Marsteller, Hsu, and Weeks 2014).

Another implication of the literature is that the impact through the change pathway (private reporting) is different from that through the reputation pathway (public reporting), which suggests that the format of public reporting matters. Therefore, an HAI reporting law mandating the disclosure of provider names is expected to generate a differential impact on provider performance.

If a hospital changed its clinical practices, we would expect to observe such changes along several dimensions. One is to apply stricter criteria for central line use to reduce unnecessary use and avoid infections. Clinicians may also improve insertion and maintenance practices, such as site selection, hand hygiene, and antiseptic skin preparation. Additionally, hospitals may allocate more resources for infection control and surveillance activities at the hospital level such as hiring more infection control specialists. Provider responses, however, do not necessarily lead to actual changes in CLABSI rates but rather changes in reporting. On the one hand, public reporting may lead to discovering more CLABSI cases that would not have been found in the absence of the reporting, which was suggested in other clinical areas (Pierce et al. 2008). On the other hand, under the public reporting pressure, hospitals may change the reporting criteria or CLABSI definition and thus "game" the system to enhance performance reports. For example, for potentially reportable CLABSI cases, hospitals may use antibiotics without ordering a blood culture and therefore avoid diagnosing such cases.

In light of the theory of public reporting and prior empirical literature, our study aimed to investigate whether the pre-law debate is associated with changes in CLABSI rates, whether the implementation of state mandatory HAI reporting laws is associated with CLABSI rates, whether public reporting with disclosure of facility identifiers matters, and whether hospitals actually changed their practices.

Methods

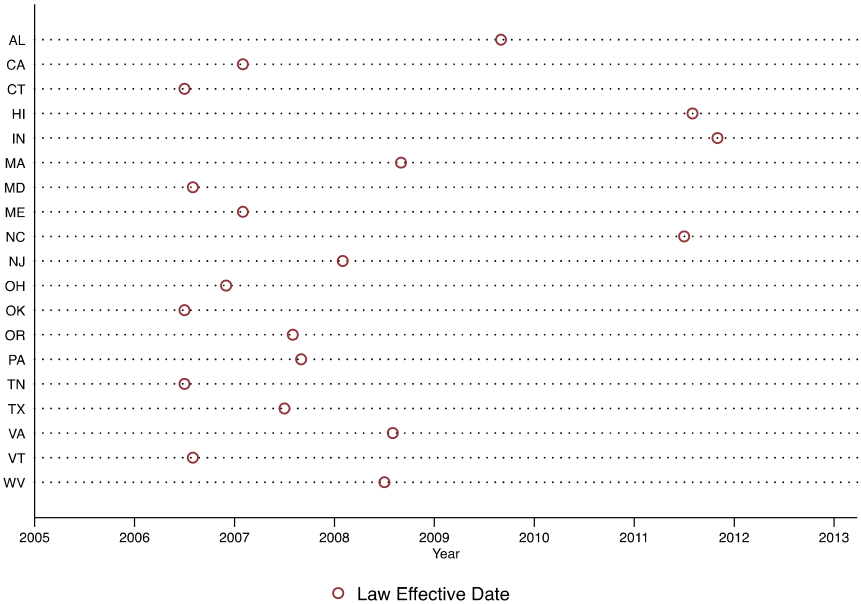
We used a quasi-experimental design to identify the effects of state HAI reporting laws on CLABSI rates in adult ICUs. Specifically, for states that implemented a reporting law prior to the end of the study period, we used data reported both before and after the laws became effective to measure changes in CLABSI rates within the same ICUs and to compare such changes in ICUs in reporting states to changes in ICUs in nonreporting states. We excluded all data from ICUs that did not voluntarily report prior to the law since those ICUs could not contribute to estimates of changes in CLABSI rates pre–post the law. Such an approach effectively removes the underlying secular trend in

CLABSI rates, which is identified by ICUs in nonreporting states. In addition, the large variation in the timing of the law effective dates across states (Figure 1) substantially strengthens the identification of the laws' effects separately from calendar time effects.

Data Sources

We analyzed 2006–2012 adult ICU CLABSI and hospital annual survey data from NHSN hospitals (Centers for Disease Control and Prevention 2015). A detailed description of enrollment and characterization of the hospitals has been previously described; briefly, all non-VA acute care hospitals enrolled in NHSN were eligible to participate (Stone et al. 2014). As per NHSN policies, each ICU contributed monthly CLABSI data but the number of observation months per ICU varied. Based on hospital administration preferences and/or state laws, ICUs may report every month or only for some *a priori* identified months. Also, some ICUs contributed data to NHSN only after their state implemented a reporting law; we excluded these ICUs since they did not have

Figure 1: Variation in the Timing of Law Effective Dates across Reporting States



data prior to the law. ICUs in Arkansas and New Mexico were also excluded because they were the only two states that had mixed voluntary/mandatory reporting schemes, and the associated sample size was small (9 ICUs and 23 ICU years). Characteristics of the hospitals came from the NHSN hospital annual survey. Data on state HAI reporting legislation, as of December 2012, were collected using multiple public sources and verified with HAI coordinators in each state's department of health (Reagan and Hacker 2012; HAI Focus 2013; Herzig et al. 2015).

Outcomes

Monthly CLABSI events weighted by patient days was the main outcome so that the potential effect of reducing central line usage could be captured; CLABSI rates were measured as the number of events per 1,000 patient days. CLABSI rates weighted by central line days and time spent by infection preventionists on infection surveillance and control activities were secondary outcomes. Infection preventionist time was measured as the reported number of hours per 100 hospital beds per week. All measures were defined as reported to the NHSN (Centers for Disease Control and Prevention 2013).

Statistical Analysis

Our statistical model was a variant of a typical difference-in-differences model that includes a treatment indicator, a treatment timing indicator (e.g., pre vs. post), and an interaction between the two indicators to capture the treatment effect. In our model, we specified ICU fixed effects, to control for time-invariant ICU-level characteristics, and a set of quarterly indicators to capture the secular trend in the outcome. Because there is substantial variation in the timing of the law effective dates across states, we created a set of indicators to reflect the time since the reporting law became effective in each ICU's state, which served as interaction terms between the timing of the law and being in a reporting state. Compared to a typical difference-in-differences model, our model allowed us to identify secular trends and time profiles of the mandate effects more robustly due to the variation in the timing of the law effective dates.

We modeled the monthly CLABSI event counts at the ICU level, specifying the model as follows. Let Y_{it} denote the outcome for ICU i at month t and assume that Y_{it} has a Poisson distribution based on a goodness-of-fit test with mean μ_{it}, where

$$\log(\mu_{it}) = \alpha_i + \beta_{q(t)} + \gamma \log(D_{it}) + \delta L_{i,s(t)}$$

In the above equation, α_i is a fixed effect for ICU i, and $\beta_{q(t)}$ is a fixed effect for calendar time, which was implemented as quarterly indicators. D_{it} is the number of patient days for ICU i and month t, the exposure variable in the Poisson regression model. $L_{i,s(t)}$ represents a series of indicators for the reporting laws, which are specified as the time since the law became effective in the ICU's state. Because the effective dates varied across states, we defined the indicators relative to each state's effective date, and in the final model, we specified the timing relative to the law effective date ($s(t)$) as a series of 6-month indicators. For example, if an ICU were in a reporting state in the 8th month after the law became effective, the indicator for "Month 6 to Month 11" would take a value of one, otherwise zero. Note that an indicator for reporting versus nonreporting state is not needed because we include ICU fixed effects (α_i). The vector δ represents the difference-in-differences estimates of the law's effect on the outcome in 6-month intervals relative to the law's effective date, which are identified separately from the calendar time effects $\beta_{q(t)}$ because of variation in effective dates across states.

All facility characteristics (e.g., profit status and type of ICU) except infection control practices were time invariant and therefore not applicable to the fixed-effect model. We did not include the infection control practice variables in the main model because they are likely on the causal pathway between the laws and CLABSI rates and including them would lead to an underestimation of the law's effect. We used sandwich estimator of variance to account for the correlation between ICUs within the same hospitals and tested the model specifications using Akaike information criterion (Akaike 1974). A significance level of 5 percent was used.

Descriptive statistics comparing the average CLABSI rates, ICU, and hospital characteristics by category using t-tests and χ^2 tests of ICUs in states with and without reporting were computed. In addition to our main analysis, several additional analyses were conducted to check the robustness of the results and explore potential explanations for the plausible effects of HAI laws. First, we examined whether the effects were similar between reporting states with and without mandated public disclosure of facility identifiers. Second, we ran a linear regression model with ICU-level fixed effects to see if the results were similar, where the dependent variable was ICU-month level CLABSI rate truncated at the 99th percentile and the number of patient days was used as an analytic weight. Third, we used central line days as the exposure in the Poisson regression model to examine whether central line utilization changed our results. Fourth, we analyzed changes in infection control practices due to law implementation to explore whether laws were associated with a shift in the time spent on HAI surveillance and other infection control activities. Finally, to determine whether any effects detected were related to hospital reporting practices (i.e., gaming), we compared only those ICU observations in states with laws that also validated CLABSI data by auditing medical records to states without laws. All analyses were conducted using *Stata, Version 13* (College Station, TX, USA).

Findings

Sample Description

As of December 2012, 32 states had mandatory HAI reporting laws (law effective dates ranging from January 2004 to October 2011) and 16 states did not have reporting laws; of those states with laws, CLABSI data were available before and after the law in 19 reporting states. And 26 reporting states (18 in the analysis) had validation processes for verifying the completeness, accuracy, and/or quality of reported CLABSI data; 12 reporting states (8 in the analysis) had a validation process for auditing medical records (Appendix Table A1) (Centers for Disease Control and Prevention 2014).

Of the 750 hospitals that enrolled and provided access to their NHSN data, 718 (1,464 ICUs) reported CLABSI data during 2006–2012 and provided NHSN annual survey data. There were no significant differences in average CLABSI rates between the study hospitals and other NHSN hospitals, although they differed by hospital size, geographic location, number of admissions, and number of ICU beds (Stone et al. 2014). After excluding ICUs in the reporting states that did not voluntarily report data prior to the law, the main analytic sample included 244 hospitals, 947 hospital years, 475 ICUs, 1,902 ICU years, and 16,996 ICU months (Appendix Table A2).

During the study period, there were an average of 36 months of CLABSI data per ICU, overall, and 9 months of CLABSI data per ICU per year, with the number of months of data reported higher in ICUs in reporting states (Table 1). Compared with ICUs in nonreporting states, those in reporting states were more likely to be affiliated with an academic medical center, nonprofit, a medical or a surgical ICU, and had a greater number of patient days and central line days. On average, over the study period, ICUs with state reporting in place had more CLABSI events and higher CLABSI rates than those in nonreporting states.

Table 1: ICU Characteristics by HAI Reporting Status, 2006–2012

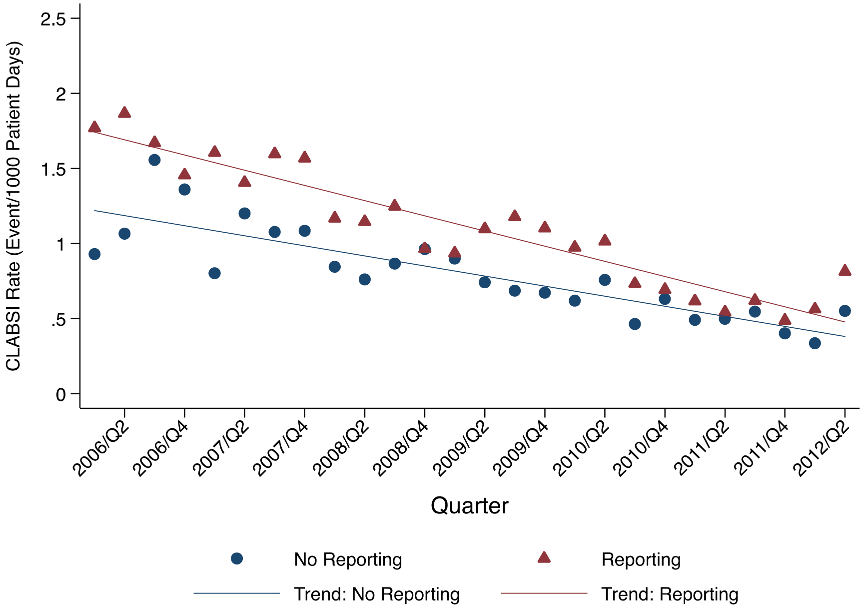
Characteristics	*No Reporting*	*Reporting*	*Total*
Number of ICU years	794	1,108	1,902
Number of months of data per ICU per year (mean, SD)†	8.40 (3.91)	9.32 (3.65)	8.94 (3.78)
General hospital (number of ICU years, %)	790 (99.50)	1,103 (99.55)	1,893 (99.53)
Affiliated with an academic medical center (number of ICU years, %)†	469 (59.07)	844 (76.17)	1,313 (69.03)
Profit status (number of ICU years, %)†			
Nonprofit	665 (83.75)	1,032 (93.14)	1,697 (89.22)
For-profit	83 (10.45)	34 (3.07)	117 (6.15)
Public	46 (5.79)	42 (3.79)	88 (4.63)
ICU type (number of ICU years, %)†			
Medical	198 (24.94)	309 (27.89)	507 (26.66)
Surgical	186 (23.43)	313 (28.25)	499 (26.24)
Medical/surgical	369 (46.47)	375 (33.84)	744 (39.12)
Burn/trauma	41 (5.16)	111 (10.02)	152 (7.99)
ICU bed size (number of ICU years, %)			
<15	478 (60.20)	685 (61.82)	1,163 (61.15)
≥15 and <30	271 (34.13)	355 (32.04)	626 (32.91)
≥30	45 (5.67)	68 (6.14)	113 (5.94)
Number of patient days per year (mean, SD)†	2,550.28 (2,152.04)	3,206.97 (2,231.68)	2,932.83 (2,221.95)
Number of central line days per year (mean, SD)†	1,384.06 (1,306.14)	1,855.36 (1,447.56)	1,658.62 (1,409.23)
Number of CLABSI events per year (mean, SD)†	1.60 (2.63)	3.27 (4.92)	2.57 (4.20)
CLABSI events per 1,000 line days (mean, SD)†	1.15 (1.23)	1.76 (2.07)	1.55 (1.84)
CLABSI events per 1,000 patient days (mean, SD)†	0.73 (0.82)	1.12 (1.45)	0.98 (1.28)

†Comparison across the two groups, $p < .01$.
CLABSI, central line–associated bloodstream infection; HAI, health care–associated infection; ICU, intensive care unit; SD, standard deviation.

Trends in CLABSI Rates

Overall, CLABSI rates decreased from an average of 1.59 infections/1,000 patient days (SD: 1.79) in the first quarter of 2006 to 0.69 (SD: 1.38) in the second quarter of 2012. As illustrated in Figure 2, ICUs in reporting states had higher rates during the study period but the rate of decline was larger (from 1.77 in the first quarter of 2006 to 0.81 in the second quarter of 2012, a 54

Figure 2: Unadjusted Trends in CLABSI Rates in Two ICU Cohorts



Notes: Central line–associated bloodstream infection (CLABSI) rates were measured as the number of CLABSI events per 1,000 patient days. The average CLABSI rate in reporting states declined from 1.77 in the first quarter of 2006 to 0.81 in the second quarter of 2012, a 54 percent reduction; the average CLABSI rate in nonreporting states decreased from 0.93 in the first quarter of 2006 to 0.55 in the second quarter of 2012, a 41 percent reduction.

percent reduction) than those in nonreporting states (from 0.93 in the first quarter of 2006 to 0.55 in the second quarter of 2012, a 41 percent reduction). When CLABSI rates were measured based on central line days, the patterns were similar, with the rate declining by 51 percent and 33 percent in reporting and nonreporting states, respectively (Appendix Figure A1).

Effect of HAI Laws on CLABSI Rates

After controlling for the secular trend and time-invariant facility characteristics, the results demonstrate that HAI reporting laws had a significant and lasting effect on decreasing reported CLABSI rates. As displayed in Table 2, compared to 25 months or more prior to the law effective date, there was a decreasing trend in CLABSI rates between 6 and 24 months prior to the law, but this was not significant. However, between 1 and 6 months prior to when

Table 2: Effect of HAI Reporting on CLABSI Rates: Poisson Regression Results

Variables	*Incidence Rate Ratio*	*Coefficient*	*Standard Error*	*p Value*
Month −25 to month −65 prior to the law effective date (reference)				
Month −19 to month −24	0.915	−0.089	0.123	.472
Month −13 to month −18	0.825	−0.192	0.117	.099
Month −7 to month −12	0.833	−0.182	0.108	.093
Month −1 to month −6	0.655	−0.422	0.117	.000
Month 0 to month 5	0.693	−0.366	0.127	.004
Month 6 to month 11	0.763	−0.270	0.130	.037
Month 12 to month 17	0.753	−0.283	0.144	.050
Month 18 to month 23	0.572	−0.558	0.163	.001
Month 24 to month 29	0.618	−0.482	0.165	.003
Month 30 to month 35	0.636	−0.453	0.184	.014
Month 36 to month 41	0.854	−0.158	0.207	.445
Month 42 to month 47	0.702	−0.354	0.234	.130
Month 48 to month 53	0.696	−0.363	0.256	.156
Month 54 to month 59	0.583	−0.540	0.300	.072
Month 60 to month 65	0.402	−0.912	0.350	.009
Month 66 to month 77	0.343	−1.071	0.410	.009

Notes. Controlled for quarterly indicators (data not shown). The dependent variable for the ICU-level fixed-effect Poisson regression model was the number of CLABSI events in each ICU month; the exposure variable was the number of patient days in each ICU month. Three single-observation ICUs and 101 ICUs with zero events in all years were excluded. The final sample included 371 unique ICUs and 15,313 observations.

the laws became effective, CLABSI rates decreased by approximately 34 percent compared with CLABSI rates in the 25 months or more prior to the law effective date (incidence rate ratio [IRR] = 0.66 [$p < .001$]). Although the effect fluctuated over time, it persisted and became larger after 4 years, with an IRR of 0.34 ($p = .009$) in the seventh year after the laws became effective.

Secondary and Sensitivity Analyses

By comparing states reporting with and without disclosure of facility identifiers (Appendix Table A3), we found a similar pattern in the law's impact on CLABSI rates as in the main analysis but fewer statistically significant coefficients; a Wald test between the two groups did not reveal any statistically significant differences. When using CLABSI rates as the dependent variable and a linear regression model (Appendix Table A4), the rates started to decline significantly during the 13–18 months prior the law effective date by 0.63 events per 1,000 patient days, compared to the rate during 25 months or more prior to the law, and the effect increased to 1.82 in the seventh year after the law. Using central line days as the exposure in Poisson regression models, we found similar results but the magnitudes of the effects were smaller (Appendix Table A5). Compared to 2 or more years prior to the law, the number of hours spent by infection control professionals per 100 hospital beds per week increased significantly, starting in 1 year prior to the law, by 2.7 hours per 100 hospital beds per week (Appendix Table A6); this effect persisted over time and by the fourth to fifth year after the law, the increase reached 8.4 hours. We found that effects became more marked than those in the main analysis by limiting to reporting states that also had data validation processes for auditing medical records and nonreporting states (Appendix Table A7).

Discussion

This is the first study to use longitudinal national data to evaluate the impact of state mandated HAI reporting laws on CLABSI rates in adult ICUs. ICUs in states with laws experienced larger declines in CLABSI rates, even after controlling for the overall decreasing trend during the study period. It is not surprising that hospitals seemed to "gear up" for mandatory reporting, with the effect appearing 6 months prior to the effective date of the law, and effects were persistent and increased for more than 6 years after the law's effective date. Our results suggest that in addition to the direct effect associated with public reporting of a hospital's infection rate, in anticipation of future public reporting, hospitals changed their practice even before the law went into effect. The reduction in CLABSI rates due to the law was 34 percent by the time the law was implemented; the reduction increased to 43 percent 2 years after implementation and to 66 percent 6 1/2 years after implementation. That is, by 2 years after implementation, over 80 percent of the reduction occurred before the law became effective; by 6 1/2 years after implementation, about 50 percent of the reduction could be attributed to the pre-law period. Therefore, the effect associated with hospital practice changes prior to the law is an important component of the law's overall effect.

We did not find significant differences in the law's impact on CLABSI rates between reporting states with mandatory disclosure of facility identifiers and those without. This may be because states without the disclosure requirement may still report facility identifiers even though the law does not specifically mandate such (Virginia Department of Health 2011; Reagan and Hacker

2012; Commonwealth of Massachusetts Department of Public Health 2013; HAI Focus 2013).

Using line days as the exposure in a secondary analysis decreased the estimated law's effect and showed that, in response to the law, hospitals reduced the use of central lines. Reducing central line utilization may be one important component of the law's impact on hospital practices. In addition, we showed that hospitals significantly increased surveillance activities by infection control preventionists. There are possibly other hospital behavioral changes that we did not observe. For example, clinicians may increase guideline adherence by improving insertion and maintenance practices such as site selection and hand hygiene. Surveying 137 hospitals located in 35 states in 2011, Linkin et al. (2013) reported no association between infection control practices and HAI reporting, possibly due to a cross-sectional study design, use of subjective perceptions, and potential confounding. Our analyses suggest that hospitals changed their practices in response to the law, but future studies are warranted.

Self-selection into HAI reporting prior to law implementation may have led to an underestimation of the law's effect. For reporting states, we only included in our analyses ICUs that voluntarily reported data prior to the law, and it is possible that the hospitals in our sample were better-performing hospitals compared to those that did not report data prior to the law. Kim and Black (2011) showed that declines in CLABSI rates were most significant in hospitals with initially higher rates. Since ICUs that voluntarily reported prior to the laws may have had lower CLABSI rates, they may have had less room to improve their rates. Similarly, in nonreporting states, nonreporting hospitals likely had higher CLABSI rates initially. However, in the absence of a reporting law, their rate declines were likely to be smaller than those who voluntarily reported data.

Due to the concern that hospitals may report CLABSI events inconsistently after the law, we limited our analysis to include only reporting states with a data validation process for medical record auditing in place and found similar results as in our primary analysis. Data validation programs may take different forms. Some states conducted data quality assessment of missing or implausible values or detection of outlier facilities. The particular validation activities of interest are those that can capture unreported events. Prior evidence suggests that such a validation process helps to ensure data quality. For example, when New York State's (not included in our analysis due to lack of data prior to the law's passage in 2005) law initially went into effect, validation led to a slight increase in reported CLABSI rates; but since then New York has seen a progressive decrease in CLABSI, and there is evidence that the data are valid (Backman, Melchreit, and Rodriguez 2010; Hazamy et al. 2013). As of 2011, New York's validation revealed 94 percent concordance with what hospitals reported (New York State Department of Health 2013). By including states with an external medical record auditing process, we found a similar or larger impact of the law, suggesting a law with a medical record auditing process may drive the reduction in CLABSI rates more than a law without such a process.

Additionally, we found improvements in other measures that are more likely to be reliable, such as reduced central line utilization and increased resources for infection surveillance. These improvements suggest a true change in infection prevention practices that make a true decrease in CLABSI rates due to mandatory reporting plausible. While it is possible that some hospitals were reporting lower CLABSI rates due to gaming/under reporting after state mandatory reporting laws went into effect, it is unlikely that this explains our results entirely.

There are limitations to this study. Although we controlled for unobserved time-invariable ICU characteristics, the potential for selection bias exists. Also, we were not able to specifically measure the potential effect of the 2008 change in the NHSN CLABSI surveillance definition (See et al. 2013); however, this change involved all hospitals in our sample and should not impact our results. Although we excluded ICUs with post-law data only, each ICU contributed monthly CLABSI data and the number of observation months per ICU varied. The concern of selective reporting may be mitigated by the fact that ICUs could either report every month or only for some *a priori* identified number of months. Moreover, in exploring the potential responses of hospitals to the mandates, we did not have data to directly examine whether selection of insertion sites, choice of catheter type, and central line maintenance practices played a role in the observed CLABSI rate reduction. Finally, federal policies that affected all states at one time, such as the CMS nonpayment policy for HAIs and the Hospital Inpatient Quality Reporting Program (Centers for Medicare and Medicaid Services 2013), may have confounded our results because only hospitals subject to the Inpatient Prospective Payment System (IPPS) were impacted by these policies and no information on IPPS status is available in our data. Over 70 percent of ICUs were located in a nonrural setting and thus were more likely to be part of an IPPS hospital, thereby mitigating the potential bias.

Robust evidence regarding the effect of mandatory HAI reporting is increasingly important to policy makers. Under the Affordable Care Act, hospital HAI rates based on NHSN data are released via the Hospital Compare website on a regular basis (Centers for Medicare and Medicaid Services 2015b). Moreover, certain HAIs are subject to financial penalties (Lee et al. 2012; Centers for Medicare and Medicaid Services 2015a) or have become part of the Value Based Purchasing program (Centers for Medicare and Medicaid Services 2014). However, until now the evidence to support this public reporting practice has been, at best, inconclusive (Ketelaar et al. 2011; Black 2012; Ryan, Nallamothu, and Dimick 2012; Totten et al. 2012; Rinke et al. 2015). In this regard, our results provide valuable evidence that reporting requirements for HAIs did improve care and the effect persisted for more than 6 years after the effective date of the mandate. Further studies are needed to further explore why and how mandatory HAI reporting laws decreased CLABSI rates, which may in turn inform how financial incentives should be designed to improve patient outcomes.

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References

Akaike, H. 1974. "A New Look at the Statistical Model Identification." *IEEE Transactions on Automatic Control* 19 (6): 716–23.

Backman, L. A., R. Melchreit, and R. Rodriguez. 2010. "Validation of the Surveillance and Reporting of Central Line-Associated Bloodstream Infection Data to a State Health Department." *American Journal of Infection Control* 38 (10): 832–8.

Berwick, D. M., B. James, and M. J. Coye. 2003. "Connections between Quality Measurement and Improvement." *Medical Care* 41 (1 Suppl): I30–8.

Black, B. 2012. "Public Reporting of HAI Rates: What We (Mostly Don't) Know." *Clinical Governance: An International Journal* 17 (2): 124–33.

Caron, A., and D. Neuhauser. 1999. "The Effect of Public Accountability on Hospital Performance: Trends in Rates for Cesarean Sections and Vaginal Births after

Cesarean Section in Cleveland, Ohio." *Quality Management in Health Care* 7 (2): 1–10.

Centers for Disease Control and Prevention. 2013. "The National Healthcare Safety Network Patient Safety Component Manual" [accessed on July 21, 2014]. Available at http://www.cdc.gov/nhsn/PDFs/pscManual/1PSC_OverviewCurrent.pdf

Centers for Disease Control and Prevention. 2014. "2012 National and State Healthcare-Associated Infection Progress Report" [accessed on May 20, 2014]. Available at http://www.cdc.gov/HAI/pdfs/progress-report/hai-progress-report.pdf

Centers for Disease Control and Prevention. 2015. "National Healthcare Safety Network (NHSN)" [accessed on August 24, 2015]. Available at http://www.cdc.gov/nhsn/datastat.html

Centers for Medicare and Medicaid Services. 2013. "Hospital Inpatient Quality Reporting Program" [accessed on December 3, 2013]. Available at http://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/HospitalQualityInits/HospitalRHQDAPU.html

Centers for Medicare and Medicaid Services. 2014. "Hospital Value-Based Purchasing" [accessed on August 24, 2015]. Available at http://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/hospital-value-based-purchasing/

Centers for Medicare and Medicaid Services. 2015a. "Hospital-Acquired Conditions" [accessed on August 24, 2015]. Available at http://www.cms.gov/Medicare/Medicare-Fee-for-Service-Payment/HospitalAcqCond/Hospital-Acquired_Conditions.html

Centers for Medicare and Medicaid Services. 2015b. "Hospital Compare" [accessed on August 24, 2015]. Available at http://www.medicare.gov/hospitalcompare/search.html

Commonwealth of Massachusetts Department of Public Health. 2013. "Health Care Associated Infections in Massachusetts Acute Care Hospitals—June 2013" [accessed on January 15, 2014]. Available at http://www.mass.gov/eohhs/gov/departments/dph/programs/hcq/healthcare-quality/health-care-facilities/hospitals/healthcare-assoc-infections/healthcare-associated-infections-reports.html

Contandriopoulos, D., F. Champagne, and J. L. Denis. 2014. "The Multiple Causal Pathways between Performance Measures' Use and Effects." *Medical Care Research and Review: MCRR* 71 (1): 3–20.

Flett, K. B., A. Ozonoff, D. A. Graham, T. J. Sandora, and G. P. Priebe. 2015. "Impact of Mandatory Public Reporting of Central Line-Associated Bloodstream Infections on Blood Culture and Antibiotic Utilization in Pediatric and Neonatal Intensive Care Units." *Infection Control and Hospital Epidemiology* 36 (8): 878–85.

HAI Focus. 2013. "State Healthcare-Associated Infection (HAI) Laws" [accessed on July 10, 2013]. Available at http://www.haifocus.com/state-healthcare-associated-infection-laws

Halpin, H. A., A. Milstein, S. M. Shortell, M. Vanneman, and J. Rosenberg. 2011. "Mandatory Public Reporting of Hospital-Acquired Infection Rates: A Report from California." *Health Affairs* 30 (4): 723–9.

Hazamy, P. A., C. Van Antwerpen, B. Tserenpuntsag, V. B. Haley, M. Tsivitis, D. Doughty, K. A. Gase, V. Tucci, and R. L. Stricof. 2013. "Trends in Validity of Central Line-Associated Bloodstream Infection Surveillance Data, New York State, 2007-2010." *American Journal of Infection Control* 41 (12): 1200–4.

Herzig, C. T., J. Reagan, M. Pogorzelska-Maziarz, D. Srinath, and P. W. Stone. 2015. "State-Mandated Reporting of Health Care-Associated Infections in the United States: Trends over Time." *American Journal of Medical Quality* 30 (5): 417–24.

Hibbard, J. H., J. Stockard, and M. Tusler. 2003. "Does Publicizing Hospital Performance Stimulate Quality Improvement Efforts?" *Health Affairs (Millwood)* 22 (2): 84–94.

Institute of Medicine. 2000. "To Err is Human: Building a Safer Health System" [accessed on January 24, 2014]. Available at http://www.iom.edu/Reports/1999/to-err-is-human-building-a-safer-health-system.aspx

Jang, W. M., S. J. Eun, C. E. Lee, and Y. Kim. 2011. "Effect of Repeated Public Releases on Cesarean Section Rates." *Journal of Preventive Medicine and Public Health* 44 (1): 2–8.

Kawai, A. T., M. S. Calderwood, R. Jin, S. B. Soumerai, L. E. Vaz, D. Goldmann, and G. M. Lee. 2015. "Impact of the Centers for Medicare and Medicaid Services Hospital-Acquired Conditions Policy on Billing Rates for Two Targeted Healthcare-Associated Infections." *Infection Control and Hospital Epidemiology* 36 (8): 871–7.

Ketelaar, N. A., M. J. Faber, S. Flottorp, L. H. Rygh, K. H. Deane, and M. P. Eccles. 2011. "Public Release of Performance Data in Changing the Behaviour of Healthcare Consumers, Professionals or Organisations." *Cochrane Database of Systematic Reviews* 11: CD004538.

Kim, H. K., and B. S. Black. 2011. "Does Hospital Infection Reporting Affect Actual Infection Rates, Reported Rates, or Both? A Case Study of Pennsylvania" [accessed on September 20, 2013]. Available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1641459

Klevens, R. M., J. R. Edwards, C. L. Richards Jr, T. C. Horan, R. P. Gaynes, D. A. Pollock, and D. M. Cardo. 2007. "Estimating Health Care-Associated Infections and Deaths in U.S. Hospitals, 2002." *Public Health Reports* 122 (2): 160–6.

Lee, G. M., K. Kleinman, S. B. Soumerai, A. Tse, D. Cole, S. K. Fridkin, T. Horan, R. Platt, C. Gay, W. Kassler, D. A. Goldmann, J. Jernigan, and A. K. Jha. 2012. "Effect of Nonpayment for Preventable Infections in U.S. Hospitals." *New England Journal of Medicine* 367 (15): 1428–37.

Linkin, D. R., N. O. Fishman, J. A. Shea, W. Yang, M. S. Cary, and E. Lautenbach. 2013. "Public Reporting of Hospital-Acquired Infections Is Not Associated with Improved Processes or Outcomes." *Infection Control and Hospital Epidemiology* 34 (8): 844–6.

Marsteller, J. A., Y. J. Hsu, and K. Weeks. 2014. "Evaluating the Impact of Mandatory Public Reporting on Participation and Performance in a Program to Reduce Central Line-Associated Bloodstream Infections: Evidence from a National Patient Safety Collaborative." *American Journal of Infection Control* 42 (10 Suppl): S209–15.

New York State Department of Health. 2013. "Hospital-Acquired Infections: New York State 2012" [accessed on June 10, 2014]. Available at https://www.health.ny.gov/statistics/facilities/hospital/hospital_acquired_infections/2012/docs/hospital_acquired_infection.pdf

Pakyz, A. L., and M. B. Edmond. 2013. "Influence of State Laws Mandating Reporting of Healthcare-Associated Infections: The Case of Central Line-Associated Bloodstream Infections." *Infection Control and Hospital Epidemiology* 34 (8): 780–4.

Pierce, C. A., E. R. Haut, S. Kardooni, D. C. Chang, D. T. Efron, A. Haider, P. J. Pronovost, and E. E. Cornwell 3rd. 2008. "Surveillance Bias and Deep Vein Thrombosis in the National Trauma Data Bank: The More We Look, the More We Find." *Journal of Trauma* 64 (4): 932–6; discussion 36–7.

Reagan, J., and C. Hacker. 2012. "Laws Pertaining to Healthcare-Associated Infections: A Review of 3 Legal Requirements." *Infection Control and Hospital Epidemiology* 33 (1): 75–80.

Rinke, M. L., D. G. Bundy, F. Abdullah, E. Colantuoni, Y. Zhang, and M. R. Miller. 2015. "State-Mandated Hospital Infection Reporting is Not Associated with Decreased Pediatric Health Care-Associated Infections." *Journal of Patient Safety* 11 (3): 123–34.

Ryan, A. M., B. K. Nallamothu, and J. B. Dimick. 2012. "Medicare's Public Reporting Initiative on Hospital Quality Had Modest or No Impact on Mortality from Three Key Conditions." *Health Affairs* 31 (3): 585–92.

Scott, R. D. II 2009. "The Direct Medical Costs of Healthcare-Associated Infections in U.S. Hospitals and the Benefits of Prevention" [accessed on December 11, 2013]. Available at http://www.cdc.gov/hai/pdfs/hai/scott_costpaper.pdf

See, I., M. Iwamoto, K. Allen-Bridson, T. Horan, S. S. Magill, and N. D. Thompson. 2013. "Mucosal Barrier Injury Laboratory-Confirmed Bloodstream Infection: Results from a Field Test of a New National Healthcare Safety Network Definition." *Infection Control and Hospital Epidemiology* 34 (8): 769–76.

Smith, M. A., A. Wright, C. Queram, and G. C. Lamb. 2012. "Public Reporting Helped Drive Quality Improvement in Outpatient Diabetes Care among Wisconsin Physician Groups." *Health Affairs* 31 (3): 570–7.

Stone, P. W., M. Pogorzelska, D. Graham, H. Jia, M. Uchida, and E. L. Larson. 2011. "California Hospitals Response to State and Federal Policies Related to Health Care-Associated Infections." *Policy, Politics & Nursing Practice* 12 (2): 73–81.

Stone, P. W., M. Pogorzelska-Maziarz, C. T. Herzig, L. M. Weiner, E. Y. Furuya, A. Dick, and E. Larson. 2014. "State of Infection Prevention in US Hospitals Enrolled in the National Health and Safety Network." *American Journal of Infection Control* 42 (2): 94–9.

Talbot, T. R., D. W. Bratzler, R. M. Carrico, D. J. Diekema, M. K. Hayden, S. S. Huang, D. S. Yokoe, N. O. Fishman, and Healthcare Infection Control Practices Advisory Committee. 2013. "Public Reporting of Health Care-Associated Surveillance Data: Recommendations from the Healthcare Infection Control Practices Advisory Committee." *Annals of Internal Medicine* 159 (9): 631–5.

Totten, A. M., J. Wagner, A. Tiwari, C. O'Haire, J. Griffin, and M. Walker. 2012. *Public Reporting as a Quality Improvement Strategy Closing the Quality Gap: Revisiting the State of the Science. Evidence Report No. 208.* Prepared by the Oregon Evidence-based Practice Center under Contract No. 290-2007-10057-I.) AHRQ Publication No. 12-E011-EF. Rockville, MD: Agency for Healthcare Research and Quality.

Virginia Department of Health. 2011. "Healthcare-Associated Infections Report October 1, 2011—December 31, 2011" [accessed on 15 January 2014]. Available at http://www.vdh.virginia.gov/epidemiology/surveillance/hai/documents/pdf/Clabsi_Summary_Report2011Q4.pdf

Supporting Information

Additional supporting information may be found in the online version of this article:

Appendix SA1: Author Matrix.

Figure A1. Unadjusted Trends in CLABSI Events Per 1,000 Central Line Days in Two ICU Cohorts.

Table A1. HAI Reporting Laws as of December 2012.

Table A2. Number of ICUs in the Final Analytic Sample by State and Year.

Table A3. Effect of HAI Reporting Law on CLABSI Rates: With and Without Disclosure of Facility Identifiers.

Table A4. Effect of HAI Reporting Law on CLABSI Rates: Linear Regression Results.

Table A5. Effect of HAI Reporting Law on CLABSI Rates: Poisson Regression Results Using Central Line Days as Exposure.

Table A6. Effect of HAI Reporting Law on Infection Control Activities: Linear Regression.

Table A7. Effect of HAI Reporting Law on CLABSI Rates: Poisson Regression Results among Reporting States with a Built-in Data Validation Process for Auditing Medical Records.