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Strict Hand Hygiene And Other Practices Shortened Stays And Cut Costs And Mortality In A Pediatric Intensive Care Unit

ABSTRACT Efforts to reduce infections acquired during a hospital stay through improvements in the quality of care have had measurable results in many hospital settings. In pediatric intensive care units, the right quality interventions can save lives and money. We found that improving practices of hand hygiene, oral care, and central-line catheter care reduced hospital-acquired infections and improved mortality rates among children admitted to a large pediatric intensive care unit in 2007–09. In addition, on average patients admitted after the quality interventions were fully implemented spent 2.3 fewer days in the hospital, their hospitalization cost \$12,136 less, and mortality was 2.3 percentage points lower, compared to patients admitted before the interventions. The projected annual cost savings for the single pediatric intensive care unit studied was approximately \$12 million. Given the modest expenses incurred for these improvements—which mainly consisted of posters for an educational campaign, a training “fair,” roughly \$21 per day for oral care kits, about \$0.60 per day for chlorhexidine antiseptic patches, and hand sanitizers attached to the walls outside patients’ rooms—this represents a significant return on investment. Used on a larger scale, these quality improvements could save lives and reduce costs for patients, hospitals, and payers around the country, provided that sustained efforts ensure compliance with new protocols and achieve long-lasting changes.

In 2008 Medicare began withholding payment to hospitals for services delivered to treat conditions resulting from what are called “never events.”¹ This change in Medicare’s payment policy was a result of efforts by the National Quality Forum to define twenty-eight never events, which are harms to a patient as a result of medical care that should rarely or never happen because they are typically preventable with low-cost, low-technology strategies.² Hospital-acquired infections for adults—such as urinary tract infections associated with the use of a catheter—were included in Medicare’s new policy

because they are detrimental to patients and costly to providers and payers.¹

Hospital-acquired infections are not limited to elderly adults. Children in pediatric intensive care units are especially vulnerable to iatrogenic infections—those caused by medical examination or treatment—that can dramatically increase morbidity, mortality, length-of-stay, and inpatient costs. Thus, children, too, could benefit greatly from improved patient safety practices.

The most common hospital-acquired infections in pediatric units are bloodstream infections associated with the use of central-line cath-

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eters, ventilator-associated pneumonia, and catheter-associated urinary tract infections. Central-line bloodstream infections are typically caused by failure to use adequate precautions to keep the lines sterile when inserting, accessing, or caring for them. Ventilator-associated pneumonia is a bacterial infection of the lungs that occurs after an endotracheal or tracheostomy tube is colonized with bacteria in a patient who is on a ventilator. Catheter-associated urinary tract infections are associated with inadequately sterile insertion and with how long the catheter is left in place.³ Costs attributable to ventilator-associated pneumonia are estimated at between \$9,969⁴ and \$25,072,⁵ while costs attributable to central-line bloodstream infections have been estimated at \$36,441.⁴

In response to the never-events policy—which, like many other Medicare policies, may be extended to Medicaid and subsequently adopted by private insurers—hospitals are implementing quality improvement initiatives to improve care for all hospital patients and to prevent never events. Such initiatives in pediatric intensive care units may inform initiatives to improve adult care because virtually all quality improvement processes encounter common barriers.

We examined the impact of implementing infection control and patient safety protocols on the clinical and financial outcomes of patients in the pediatric intensive care unit. We hypothesized that by simultaneously implementing improved hand hygiene and standardized care protocols for patients on ventilators and patients with central-line catheters, hospitals could reduce rates of hospital-acquired infections, lengths-of-stay, inpatient costs, and in-hospital mortality and improve the care provided.

The results of this study demonstrate the business case for improved hand hygiene and standardized patient care—two changes in the process of care that dramatically improved a comprehensive range of clinical and economic outcomes. These results may assist other hospitals' efforts to reduce the occurrence of never events in other units, and to reduce hospital-acquired infections in the pediatric intensive care unit. And the policy implications of our findings will be broader if, as is likely, Medicaid and private insurers adopt similar never-events payment policies.

Study Data And Methods

STUDY SETTING AND INTERVENTIONS We conducted this study in a multidisciplinary pediatric intensive care unit at the Women's and Children's Hospitals at the University of North Carolina that averages 1,000–1,200 admissions per year. At the beginning of the study, in

January 2007, the unit had sixteen beds; it expanded to twenty beds in September 2009. All patients were managed by a pediatric intensivist, either alone or in conjunction with the admitting surgeon or referring pediatric specialist. No changes in personnel in the unit occurred during the study period.

► **THREE INTERVENTIONS:** The study's first intervention was enforcing strict compliance with standard practices of hand hygiene. These practices—hereafter simply called “hand hygiene”—consist of carefully cleaning the hands with soap and running water, or an alcohol-based rub, to remove visible soil and remove or kill transient microorganisms, such as bacteria. All health care workers are expected to perform hand hygiene on entering and leaving a patient's room, before donning and on removing gloves, and before and after any task that involves touching potentially contaminated surfaces or body fluids.

The second intervention was implementing the ventilator-associated pneumonia “bundle” of the Institute for Healthcare Improvement.⁶ This consists of the following preventive measures: (1) Elevating the head of the patient's bed when he or she is put on the ventilator, which helps decrease secretions and gastric contents from pooling in the back of the mouth. (2) Giving the patient daily “sedation vacations”—or breaks from sedation with medications—which allows the medical team to assess the patient's mental status. (3) Coupled with the “sedation vacation,” assessing the patient's readiness to come off the ventilator. Sedative medications decrease the drive to breathe, such that the most accurate method of determining readiness for removing the breathing tube is possible only while the patient is reasonably awake. (4) Applying measures as needed to prevent peptic ulcer disease and deep vein thrombosis—complications that prolong ventilation and increase the risk of developing ventilator-associated pneumonia. (5) Providing daily oral care with chlorhexidine, a long-lasting antiseptic, which dramatically limits bacterial overgrowth in the oral pharynx of the ventilated patient.

The final intervention was ensuring compliance with care practices in standard guidelines for accessing and maintaining the dressings for central-line catheters. This consisted of placing sponges impregnated with chlorhexidine on the central-line insertion cart, using second-generation catheters impregnated with antibiotics whenever possible, and adding as a new goal on the daily goals form and to rounds in the unit at least two assessments per day of whether patients with central-line catheters still needed them.

Hospitals are implementing initiatives to improve care for all hospital patients and to prevent never events.

► **DEVELOPING AND REVIEWING THE INTERVENTIONS:** Two teams—consisting of doctors, nurses, and house staff in the unit—led the development of the interventions, which were designed and conducted in accordance with Six Sigma principles to reduce the rates of ventilator-associated pneumonia and central-line bloodstream infection. In Six Sigma, the improvement process is precise and detailed, following a basic framework consisting of the following phases: define, measure, analyze, improve, and control. This process ensures that the appropriate cause or causes of a problem are identified and changed, and that the changes are maintained.⁷⁻⁹

The ventilator-associated pneumonia and central-line bloodstream infection projects that led to the implemented interventions are detailed in the Appendix, available online.¹⁰ Although multiple definitions have been applied to both of these infections, we chose to employ the Standard National Healthcare Safety Network definitions.^{11,12}

Independent hospital epidemiology and infection preventionists reviewed all cultures from patients showing signs of ventilator-associated pneumonia or central-line bloodstream infection during the baseline period, explained below. The reviewers found that the length of time a patient spent on the ventilator was positively associated with the risk of ventilator-associated pneumonia. Ninety-five percent of the central-line bloodstream infections developed more than forty-eight hours after the insertion of the catheter, which meant that they were associated with maintenance and care of the catheter rather than its insertion.

The review was followed by direct observations of care delivery. Focus groups of physicians and nurses identified individual staff members' lack of knowledge about caring for patients on ventilators, caring for central-line catheters, and hand hygiene. Before implementing the inter-

ventions, we held an educational “fair” to address the knowledge deficits by demonstrating appropriate hand hygiene and oral care and providing education on the ventilator-associated pneumonia bundle, with particular attention to elevation of the head of the bed.

To increase individual accountability, we followed the fair with staff members' self-assessments of hand hygiene, care of patients on ventilators, and care of central-line catheters. Finally, with the full support of the hospital administration, we developed and disseminated standardized care protocols to implement the interventions (see the Appendix).¹⁰

Dashboards that tracked trends in hand hygiene, oral care, head of bed elevation, central-line care, number of days since the last case of ventilator-associated pneumonia, and number of days since the last case of central-line bloodstream infection were conspicuously posted in the pediatric intensive care unit (see the Appendix for an example).¹⁰ They were visible to patients and their families as well as to staff members, reinforcing the staff's accountability for the performance of the pediatric intensive care unit.

STUDY SAMPLE This retrospective cohort study included all children admitted to the pediatric intensive care unit between January 1, 2007, and December 31, 2009, for whom we had complete data ($N = 2,397$). We divided the sample to reflect three distinct study periods: the baseline period, from January 1, 2007, to January 31, 2008; the intervention period, from February 1, 2008, to October 31, 2008, when the interventions were being implemented; and the post-intervention period, from November 1, 2008, to December 31, 2009, when all interventions were in place. Of the 2,397 patients in the sample, 817 were admitted in the baseline period, 601 in the intervention period, and 961 in the postintervention period.

In a sensitivity analysis, we divided the study period into twelve quarter-years to enable a time-series analysis with consistent units of time within the sample. In a separate sensitivity analysis, we examined the association of the interventions and outcomes for patients who never developed a hospital-acquired infection, to determine whether the benefits of the interventions extended to them.

OUTCOMES AND EXPLANATORY VARIABLES We had already selected the outcome variables and analyses for the study when we implemented the interventions. Despite the prospective conduct of the intervention, the evaluation was based on a retrospective cohort design so that we could evaluate outcomes in the baseline period as well as in the intervention and postintervention periods. The only data we collected prospectively

concerned compliance with the interventions.

We evaluated both clinical and economic outcomes. The clinical outcomes were the probability that a patient in the pediatric intensive care unit would develop ventilator-associated pneumonia or a central-line bloodstream infection; would have respiratory failure, which would require the patient to be put on a ventilator; and would die during his or her stay in the unit. The economic outcomes were the number of days a patient in the unit was on a ventilator, length-of-stay in the unit, total length-of-stay in the hospital, cost of the stay in the unit, and total cost of the hospital stay.

We estimated costs by applying the hospital-specific cost-to-charge ratio to reported charges. We used estimated costs instead of health plan data on reimbursements or expenditures because we had access to hospital cost accounting data but not to health plan claims data. Thus, the

cost analysis is based on the perspective of the hospital, rather than that of the payer. We adjusted all costs to 2010 dollars, using the Consumer Price Index to account for inflation.

The explanatory variables of interest were the three study period indicators—baseline, intervention, and postintervention. We also adjusted for patient age, sex, and race; insurance coverage; comorbidity, using the validated All Patient Refined Diagnosis Related Groups Death Risk Score;¹¹ and the primary specialty of the treating provider (pediatric critical care, pediatric cardiothoracic surgery, pediatric surgery or neurosurgery, or other). We included the same explanatory variables in all regressions.

ANALYSIS Using the statistical software Stata (version 11.0), we calculated descriptive statistics (*t* tests and chi-square tests) of patient covariates to examine whether patient factors (Exhibit 1) and unadjusted outcomes (Exhibit 2)

EXHIBIT 1

Demographics Of Patients Admitted To A Pediatric Intensive Care Unit, 2007-09

| Sample characteristics | Study period | | | Total (1/1/07-12/31/09) |
|---|------------------------------|-----------------------------------|--|----------------------------|
| | Baseline (1/1/07-1/31/08) | Intervention (2/1/08-10/31/08) | Postintervention (11/1/08-12/31/09) | |
| Number of patients | 817 | 601 | 961 | 2,379 |
| Female | 44.8% | 43.1% | 43.7% | 43.9% |
| AGE (YEARS) | | | | |
| 0-<1 | 35.9% | 30.3% | 30.0% | 32.0% |
| 1-<5 | 24.9 | 26.5 | 24.4 | 25.1 |
| 5-<12 | 17.2 | 19.3 | 22.0** | 19.6 |
| 12-25 | 22.0 | 24.0 | 24.0 | 23.3 |
| RACE OR ETHNICITY | | | | |
| White | 46.5% | 42.8% | 46.8% | 45.7% |
| Black | 27.5 | 27.1 | 24.9 | 26.4 |
| Hispanic | 13.2 | 14.6 | 12.2 | 13.1 |
| Other | 12.7 | 15.5 | 16.1 | 14.8 |
| INSURANCE | | | | |
| Medicaid | 57.8% | 60.2% | 57.0% | 58.1% |
| Blue Cross | 6.5 | 6.7 | 7.7 | 7.0 |
| Other private | 6.8 | 7.1 | 10.5*** | 8.4 |
| Self-pay | 11.9 | 10.8 | 13.9 | 12.4 |
| Other | 17.1 | 15.1 | 10.8**** | 14.0 |
| APR DEATH RISK SCORE | | | | |
| 1 | 47.0% | 49.7% | 46.4% | 47.5% |
| 2 | 23.6 | 22.1 | 23.6 | 23.2 |
| 3 | 18.4 | 16.5 | 19.5 | 18.3 |
| 4 | 11.0 | 11.6 | 10.5 | 11.0 |
| PRIMARY SPECIALTY OF TREATING PROVIDER | | | | |
| Pediatric critical care | 37.2% | 30.1%*** | 34.8% | 34.4% |
| Pediatric surgery/neurosurgery | 13.0 | 19.5**** | 19.6**** | 17.3 |
| Pediatric cardiothoracic surgery | 17.3 | 14.8 | 13.8 | 15.2 |
| Other | 32.6 | 35.6 | 31.8 | 33.1 |

SOURCE Authors' analysis of study data. **NOTES** APR death risk is All Patient Refined Diagnosis-Related Groups Death Risk Score (see Note 11 in text). A score of 1 means a child is at a minor risk of death; a score of 2 means a moderate risk of death; a score of 3 means a major risk of death; and a score of 4 means an extreme risk of death. Percentages might not sum to 100 because of rounding. Other insurance included Medicare, state employees' EDS coverage, other agency, and not otherwise specified. *p* values indicate differences between each period and the subsequent period. ***p* < 0.05 ****p* < 0.01 *****p* < 0.001

EXHIBIT 2
Unadjusted Outcomes Of Patients Admitted To A Pediatric Intensive Care Unit (PICU), 2007-09

| Sample characteristics | Study period | | | Total (1/1/07-12/31/09) |
|---|------------------------------|-----------------------------------|--|----------------------------|
| | Baseline (1/1/07-1/31/08) | Intervention (2/1/08-10/31/08) | Postintervention (11/1/08-12/31/09) | |
| Number of patients | 817 | 601 | 961 | 2,379 |
| In-hospital deaths | 6.4% | 6.0% | 4.0%** | 5.3% |
| Average days on ventilator | 5.0 (±0.5) | 3.5 (±0.3)** | 2.8 (±0.2)**** | 3.7 (±0.2) |
| MORBIDITY | | | | |
| On ventilator | 52.0% | 47.1% | 39.0% | 45.6% |
| Ventilator-associated pneumonia ^a | 1.9 | 2.6 | 0.7*** | 1.6 |
| Central-line bloodstream infection ^b | 3.8 | 3.1 | 1.6**** | 2.7 |
| AVERAGE LENGTH-OF-STAY (DAYS) | | | | |
| In PICU | 6.9 (±0.5) | 5.5 (±0.4) | 5.0 (±0.2)**** | 5.8 (±0.2) |
| In hospital | 16.6 (±0.9) | 13.4 (±0.8)** | 12.8 (±0.6)**** | 14.3 (±0.5) |
| AVERAGE COST OF STAY (2010 US\$) | | | | |
| In PICU | 34,365 (±2,446) | 30,175 (±2,139) | 25,938 (±1,146)*** | 29,919 (±1,105) |
| In hospital | 54,323 (±3,217) | 46,773 (±2,727) | 42,071 (±1,700)**** | 47,466 (±1,475) |

SOURCE Authors' analysis of study data. **NOTE** Numbers in parentheses represent standard deviations. *p* values indicate differences between the baseline and other periods. ^aPer 1,000 days on a ventilator. ^bPer 1,000 days with a catheter. ***p* < 0.05 ****p* < 0.01 *****p* < 0.001

varied by study period. We conducted regression analyses to identify adjusted differences in outcomes between the study periods after controlling for the covariates described above.

We estimated the three dichotomous outcomes—ventilator-associated pneumonia, central-line bloodstream infection, and mortality—via logistic regression. We estimated zero-inflated Poisson regressions for number of days on a ventilator because a high proportion of patients were never ventilated. We used negative binomial regressions to estimate length-of-stay in the pediatric intensive care unit and in the hospital. We estimated the cost of stay in the unit and the hospital via generalized linear models with a gamma distribution and log link function, to account for the non-normality of the cost distributions.¹³

This study was approved by the Institutional Review Board of the University of North Carolina at Chapel Hill.

LIMITATIONS The study is subject to some limitations. First, it did not include a control hospital or set of hospitals, so the changes that we observed may have been driven in part by other simultaneous changes in this hospital—such as increased leadership interest in hospital-wide efforts to improve quality—that reinforced the impact of the interventions we evaluated. Future research should be conducted to isolate the causal effect of general quality improvement efforts and to determine the validity of our findings in other hospitals.

Second, changes in outcomes may have been influenced by secular trends—for example, changes in the risk of hospital-acquired

infection—driven by other simultaneous interventions that improved care for patients who did not develop such an infection, or by patient factors that were not observed in the covariates based on claims data that we used in our regressions.

Third, we observed few differences among the patients in the three study periods, but there may be unmeasured factors that we could not control for that confounded the intervention effects. Notably, patient case-mix, as measured by the All Patient Refined Diagnosis Related Groups Death Risk Score,¹¹ was similar during all three periods. The risk adjuster we used may have explained less variance in outcomes than two other commonly employed pediatric physiologic outcome measures, the Pediatric Risk of Mortality III and the Pediatric Index of Mortality-2.^{14,15} Researchers interested in validating our results should consider using either of those measures.

Finally, the study results may not generalize to other hospitals that implement these same interventions, because our sample consisted of patients in a single hospital.

Study Results

PATIENT CHARACTERISTICS Patients in the baseline, intervention, and postintervention periods were similar in most respects (Exhibit 1). There were more patients under one year of age in the baseline period than in the other two periods and fewer patients in the age group five years to under twelve years in the baseline period than in the other two periods. More patients were admitted by pediatric surgeons or

neurosurgeons in the intervention and postintervention periods than in the baseline period. Patients in the postintervention period were more likely than patients in the baseline period were to have private insurance but were less likely to have insurance in the “other” category. This included Medicare, state employees’ EDS coverage, other agency, and not otherwise specified. Notably, the death risk scores were similar across the three periods.

UNADJUSTED OUTCOMES The unadjusted outcomes generally favored the intervention and postintervention periods (Exhibit 2). Patients in the postintervention period were less likely than patients in the baseline period to be on a ventilator or to have ventilator-associated pneumonia or a central-line bloodstream infection, or to die in the hospital. Postintervention patients also spent fewer days on a ventilator than patients in the baseline period.

In addition, postintervention patients had a lower unadjusted average length-of-stay in the pediatric intensive care unit and in the hospital than baseline patients (Exhibit 2). These unadjusted differences in length-of-stay were reflected in the unadjusted mean costs for stays in the pediatric intensive care unit and in the hospital.

ADJUSTED PATIENT OUTCOMES FROM REGRESSIONS The differences in unadjusted outcomes between the baseline and intervention periods were largely confirmed in multivariate regressions (Exhibit 3). When we controlled for patient and provider factors, patients in the intervention period spent 2.2 fewer days in the hospital and 1.0 fewer days on a ventilator than patients in the baseline period.

Patients in the postintervention period did better than patients in the baseline period on all of the outcomes we investigated (Exhibit 3). They had lower odds of having ventilator-associated pneumonia or central-line bloodstream infection and of being on a ventilator, as well as significantly lower odds of dying in the hospital. In addition, their average length-of-stay was 0.8 days shorter in the pediatric intensive care unit and 2.3 days shorter in the hospital altogether, and their average adjusted costs were lower (\$8,826 for the unit and \$12,136 total). It was necessary to adjust our cost analysis because of the different number of patients in each period.

SENSITIVITY ANALYSES We conducted a sensitivity analysis to examine whether these changes in patient safety improved outcomes for all patients in the pediatric intensive care unit, both those who did have a hospital-acquired infection

EXHIBIT 3

Adjusted Outcomes Of Patients Admitted To A Pediatric Intensive Care Unit (PICU), 2007-09

| Outcomes | Regression model | Intervention period (2/1/08-10/31/08) | Postintervention period (11/1/08-12/31/09) |
|------------------------------------|-----------------------|--|---|
| CLINICAL OUTCOMES | | | |
| Ventilator-associated pneumonia | Logistic | 1.44 (0.71, 2.92) ^a | 0.37 (0.15, 0.97) ^{a***} |
| Central-line bloodstream infection | Logistic | 0.86 (0.48, 1.53) ^a | 0.42 (0.22, 0.80) ^{a****} |
| Mortality | Logistic | 0.79 (0.45, 1.39) ^a | 0.51 (0.30, 0.85) ^{a***} |
| USE OUTCOMES | | | |
| Average days on ventilator | Zero-inflated Poisson | -1 (-1.8, -0.2) ^{a,b***} | -1.7 (-2.5, -0.9) ^{b***} |
| Probability of being on ventilator | Logistic | 0.88 (0.68, 1.13) ^b | 0.52 (0.41, 0.66) ^{b****} |
| Length-of-stay PICU | Negative binomial | -0.6 (-1.2, 0.03) ^b | -0.8 (-1.4, -0.2) ^{b***} |
| Total | Negative binomial | -2.2 (-3.4, -0.7) ^{b****} | -2.3 (-3.6, -1.0) ^{b****} |
| COST OUTCOMES | | | |
| PICU cost | GLM | -3,948 (-10,678, 2,782) ^c | -8,826 (-13,950, -3,702) ^{c****} |
| Total cost | GLM | -7,697 (-15,990, 597) ^c | -12,136 (-19,058, -5,214) ^{c****} |

SOURCE Authors’ analysis of study data. **NOTES** Mortality is in-hospital deaths. Total is all hospital, including PICU. Costs are in 2010 US dollars. Reductions in the outcomes were significant after controlling for different sample sizes and confounding variables. GLM is generalized linear model. ^aOdds ratio (95% confidence interval). ^bPredicted difference in outcome, such as number of days on a ventilator (95% confidence interval). ^cPredicted difference in costs (95% confidence interval). ***p* < 0.05 ****p* < 0.01 *****p* < 0.001

EXHIBIT 4
Sensitivity Analysis Of Unadjusted Outcomes Of Patients Admitted To A Pediatric Intensive Care Unit (PICU), 2007-09

| Period | Number of patients | Average length-of-stay (days) | | Average cost (\$1,000s) | | In-hospital deaths (%) |
|---|--------------------|-------------------------------|----------------|-------------------------|---------------|------------------------|
| | | PICU | Total | PICU | Total | |
| NO INFECTION | | | | | | |
| Baseline | 771 | 5.4 (±0.3) | 14.5 (±0.8) | 28.4 (±1.8) | 47.0 (±2.5) | 6.1 |
| Intervention | 557 | 4.5 (±0.3)** | 11.8 (±0.6)*** | 25.1 (±1.5) | 41.0 (±2.1) | 5.2 |
| Postintervention | 911 | 4.8 (±0.2)** | 12.5 (±0.6)** | 24.7 (±1.1) | 41.0 (±1.6)** | 3.8** |
| VENTILATOR-ASSOCIATED PNEUMONIA | | | | | | |
| Baseline | 16 | 32 (±10) | 54 (±12) | 134 (±37) | 176 (±5) | 0.0 |
| Intervention | 16 | 36 (±11) | 57 (±15) | 168 (±45) | 213 (±52) | 31.2** |
| Postintervention | 7 | 25 (±9) | 42 (±18) | 108 (±39) | 149 (±63) | 14.3 |
| CENTRAL-LINE BLOODSTREAM INFECTION | | | | | | |
| Baseline | 31 | 39 (±9) | 60 (±12) | 161 (±38) | 205 (±46) | 16.1 |
| Intervention | 19 | 31 (±10) | 48 (±15) | 129 (±43) | 162 (±51) | 15.8 |
| Postintervention | 15 | 10.9 (±3.5)** | 15.1 (±4.7)** | 47 (±15)** | 57 (±17)** | 6.7 |

SOURCE Authors' analysis of study data. **NOTES** The three infection groups were separated and logic regressions were reapplied. Total is all hospital, including PICU. Numbers in parentheses represent standard deviations. Costs are in 2010 US dollars. ** $p < 0.05$ *** $p < 0.01$

and those who did not. We found that patients without hospital-acquired infections in the post-intervention period had a length-of-stay in the unit that was 0.6 days shorter (4.8 versus 5.4 days) than patients without hospital-acquired infections in the baseline period, and a total length-of-stay in the hospital that was 2.0 days shorter (12.5 versus 14.5 days) (Exhibit 4). Total inpatient costs for patients without hospital-acquired infections were \$6,000 less in the post-intervention period than in the baseline period, and mortality was 2.3 percentage points lower.

In an additional sensitivity analysis, we divided the sample into twelve quarter-years based on the patient's admission day to conduct a time-series analysis with consistent units of time within the sample. Nearly all results were consistent with those reported above, with the exception of rates of ventilator-associated pneumonia, central-line bloodstream infection, and mortality. These outcomes became insignificant, although they were close to being significant (see the Appendix).¹⁰

Discussion

IMPROVED CLINICAL OUTCOMES AND REDUCED COSTS Previous studies have demonstrated the benefits of reducing hospital-acquired infections in the intensive care unit through improved hand hygiene, proper oral care, and maintenance care for central-line catheters.¹⁶⁻²³ This study contributes to and extends the prior literature. We demonstrated that these changes in the process of care for patients in the pediatric intensive care unit significantly improved patient outcomes in terms of reduced rates of hospital-

acquired infections and in-hospital mortality, reduced length-of-stay, and lower inpatient costs. Given the similarities of the patient populations across the study periods, this finding is striking.

These meaningful improvements were achieved using low-cost and established methods of standardizing protocols designed to improve the care of patients in the pediatric intensive care unit. In patients on a ventilator, proper oral care was implemented by adopting the Institute for Healthcare Improvement ventilator "bundle."^{6,24}

In patients with central-line catheters, reductions in associated bloodstream infections occurred after implementing an established procedure to care for and access these devices. Hand hygiene was identified as a key target for quality improvement efforts in the pediatric intensive care unit. Infection rates dropped noticeably once a hand hygiene policy was actively enforced, which included written notices to repeat offenders. Chief medical and nursing officers of the hospital championed this policy.

Getting nurses in the unit to "buy in" was crucial for these projects. That process was greatly facilitated by having nurses champion at least some of these processes and assume responsibility for writing the new policies. They also established quality improvement initiatives based on nursing care that included weekly audits of compliance with the new interventions. All of the audit results were posted in real time on the dashboard in the pediatric intensive care unit that we described above.

The cost reductions are particularly striking, and they suggest that a strong business case can

be made for these quality improvement processes. The average cost per hospital stay in the postintervention period was \$12,136 lower than the baseline sample (Exhibit 3). These sums represent a significant return on investment, given that the modest expenses incurred for these improvements were for an educational campaign that consisted of posters and a fair, described above; roughly \$21 per day for oral care kits; and about \$0.60 day for chlorhexidine patches and hand sanitizers attached to the walls outside patients' rooms.

Of this \$12,136 cost reduction, \$1,910 came in the form of reduced laboratory and pharmaceutical costs (data not shown). Because Medicaid and other payers reimburse hospitals using a fixed per diem payment or one based on diagnosis-related group, a \$1,910 reduction in a hospital's cost for each patient in the pediatric intensive care unit creates a substantial improvement in the hospital's operating margin. The remaining \$10,226 in savings resulted from reduced length-of-stay, which benefits patients and payers directly. The projected annual cost savings for this single pediatric intensive care unit was approximately \$12 million, vastly exceeding the \$1.1–\$2.7 million in cost savings projected in a simulation study of the Centers for Medicare and Medicaid Services' never-events policy for Medicare beneficiaries in the entire country.²⁵

POLICY IMPLICATIONS These results have two specific policy implications. First, large improvements were seen in rates of ventilator-associated pneumonia, central-line bloodstream infection, and in-hospital mortality. Future research should examine these outcomes in larger samples across multiple institutions to validate our results. However, the results suggest that efforts to encourage hospitals to implement practical and low-cost strategies to reduce hospital-acquired infections have the potential to save lives and money.

Since Medicare's never-events payment policy change, various health care institutions have succeeded in reducing many of what were once considered common acceptable risks in health care, including ventilator-associated pneumonia and central-line bloodstream infections. The change has the potential to motivate hospitals to make improvements in patient care that will benefit patients and health systems themselves, especially if Medicaid and private insurers adopt a similar policy.²⁶

Second, these results demonstrate that implementing interventions to reduce hospital-acquired infections will improve the care of all patients, not just those at risk for these infections. In the postintervention period, even pa-

Efforts to encourage hospitals to implement practical and low-cost strategies have the potential to save lives and money.

tients who never developed a hospital-acquired infection had an average length-of-stay that was two days shorter than patients without such infections in the baseline period, as well as lower mortality rates (6.1 percent versus 3.8 percent) and cost savings of about \$6,000 per patient (Exhibit 4).

LESSONS FOR FUTURE INTERVENTIONS Numerous studies have shown that the standardization of care practices improves patient outcomes.^{7,11,16,19,22,26} The Centers for Disease Control and Prevention and the World Health Organization have been advocating such standardization, as well as improved hand hygiene, for some time.^{27,28} However, improvements in patient outcomes are modest and short-lived unless the quality improvement initiative is properly launched. During the implementation and evaluation of our three Six Sigma interventions, we learned several lessons that may inform similar interventions at other hospitals and the implementation of additional interventions at the hospital in our study.

First, the hospital administrator's support for the interventions in our study was essential. The involvement of a senior administrator affirmed the importance of the project in general. In particular, it removed barriers—such as delays in purchasing equipment—and encouraged health care workers to urge even their colleagues of higher rank to use hand hygiene. It also produced a greater level of accountability and buy-in at all levels, which made it easier to change clinical cultures and practices.

Second, without regular and repeated follow-up, people return to old habits. This means that sustained efforts are needed to ensure compliance with new protocols and attain long-lasting changes.

Third, the success of the intervention and returns on the investment depend on staff mem-

bers' investment in the change. For example, the early observations, surveys, and focus groups in our study all demonstrated to staff members where improvements needed to be made. This fostered open discussions among staff members, which in turn produced clear guidelines and standards. In addition, when physicians and other personnel from outside the pediatric intensive care unit did not comply with hand hygiene and a staff member identified the problem, the attending physician in the unit would either back the staff member up or initiate a dialogue with the noncompliant colleague, following up as needed. The bedside staff members in the unit recognized the importance of these initiatives and understood that the unit's physicians sup-

ported them in trying to achieve compliance.

CONCLUSION At present, about 15 percent of all hospital beds are in intensive care units and account for 152 million patient-days per year, which cost roughly \$81 billion in 2005.²⁹ Should future efforts to improve quality replicate on a larger scale the results we have reported here, it would be possible to reduce critically ill patients' average length-of-stay by 21 percent (Exhibit 3). In terms of cost savings alone, that change would certainly improve our national well-being. Moreover, standardizing policies for patient care and improving provider education about and compliance with those policies could reduce the rate of hospital-acquired infections and benefit patients, providers, and payers alike. ■

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In this month's *Health Affairs*, Bradford Harris and coauthors report that putting in place better hand hygiene, oral care, and central-line catheter care reduced hospital-acquired infections among children admitted to the large pediatric intensive care unit at the University of North Carolina at Chapel Hill. Patients admitted after the new interventions were implemented had lower rates of ventilator-associated pneumonia and central-line infection. Mortality dropped 2.3 percentage points, and hospital stays were 2.3 days shorter and cost \$12,136 less,

compared to other stays before the interventions began. All that resulted in a large return on investment, given the modest costs of the changes that were put in place.

"Getting doctors, nurses, and hospital technicians to change their ingrained habits took the support of the hospital's chief medical officer, chief nursing officer, and other administration executives," says Harris, a medical officer at the Food and Drug Administration. "We saw big changes from really simple stuff, such as more hand washing. There was even a period from February 2010 to March 2011 where we reduced ventilator-associated pneumonias from twelve or fifteen per year to zero."

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