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ORIGINAL ARTICLE

Reducing Hospital-Acquired Infections Among the Neurologically Critically Ill

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Abstract

Background Hospital-acquired infections (HAIs) result in excess morbidity, mortality, and resource consumption. Immobilized, ventilator-dependent ICU patients are at the highest risk of HAI.

Methods Despite broad implementation of relevant bundles, HAI incidence in our neuro ICU remained high, particularly catheter-associated urinary tract infections (CAUTIs) and ventilator-associated events (VAEs). We reviewed the administrative data and nosocomial infection markers (NIMs) for all neurology and cranial neurosurgery patients admitted to our neuro ICU between January 2011 and May 2014, identified and implemented interventions, and measured effects using National Healthcare Safety Network (NHSN)-defined CAUTIs and VAEs. Interventions included (1) reviewing Foley catheter use, including indications and alternatives, and instituting daily rounds, continuously questioning the ongoing need for a catheter; (2) re-educating neuro ICU personnel in insertion and maintenance technique, introducing a new kit that simplified and standardized sterile insertion; and (3) placing a mobile CT in the neuro ICU since our patients required repeated transports for brain imaging and since we found correlations between frequencies of these transports, and both respiratory and urinary NIMS.

Results VAEs decreased 48 %, Foley use decreased 46 %, CAUTIs decreased from 11/1000 catheter days to 6.2. Overall complication rate decreased 55 %, ICU length of stay 1.5 days, and risk-adjusted mortality 11 %.

Conclusions Combining a multidisciplinary approach with rigorous analysis of objective data, we decreased total HAIs by 53 % over 18 months. Key drivers were decreased urinary catheter use and decreased patient transport from the ICU for imaging.

Keywords Hospital-acquired infections · Neurocritical care · CAUTI · Ventilator-associated events · Reduction

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Background

The management of critically ill patients with severe central nervous system insults has advanced dramatically in recent years. However, morbidity and mortality remain substantial. These patients are often bedridden and immobilized, frequently requiring ventilator support for extended periods of time. Such patients are at high risk of hospital-acquired infections (HAIs), particularly pulmonary [1, 2] and urinary [3, 4] infections. These in turn can prolong hospitalization [5] and increase the risk of additional complications and death. Despite widespread utilization of bundles of care for ventilator [6], central line, and other aspects of care [7], HAIs still occur with some frequency in this population.

These issues have been of particular concern in our institution—a Joint Commission-designated Comprehensive Stroke Center and regional referral center for neurologic disorders—where we have a large population of very ill patients with intracranial hemorrhages, large ischemic strokes, and other severe nontraumatic brain injuries (Table 1), with over 2000 patients admitted

Table 1 Principal diagnoses in the prospective patient group (% of each patient group with a given diagnosis, January 2013–March 2016)

	All neuro ICU ($n = 1.913$)	Ventilator ($n = 393$)
Hemorrhagic stroke	17 % ($n = 329$)	14 % ($n = 58$)
Ischemic stroke	18 % ($n = 338$)	10 % ($n = 41$)
Aneurysm repair	14 % ($n = 276$)	24 % ($n = 94$)
Seizures	3 % ($n = 64$)	9 % ($n = 34$)
Other intracranial neurosurgery	51 % ($n = 982$)	60 % ($n = 236$)
Other	11 % ($n = 20$)	7 % ($n = 26$)

annually with primary diagnoses of neurological or cranial neurosurgical disorders; of these patients, more than one in four require a stay in our critical care unit—a dedicated 10-bed neurosciences intensive care unit (neuro ICU) staffed by two fellowship-trained neurointensivists. In this group of patients, 458 required mechanical ventilation during their ICU stay during our pilot study. The range of diagnoses and other demographic information are summarized in Tables 1 and 2.

In trying to decrease the incidence of HAIs, the first challenge is accurate measurement [8]—to understand the magnitude of the problem, to benchmark performance against other institutions with comparable patient populations, to identify specific aspects of care that are the most problematic, and to measure changes in outcome in response to interventions. Although administrative data are the most readily available, these have well-appreciated limitations of sensitivity and specificity—limitations that become increasingly confounding the smaller the sub-population being studied. For a number of years, our institution used the reproducible and explicitly defined Nosocomial Infection Marker (NIM) methodology (CareFusion Inc., San Diego CA) as a surrogate measure of pulmonary and urinary infections. This method is probably more sensitive than specific, but as an objectively defined laboratory-test-based approach, it is internally consistent and sufficiently reproducible to permit temporal trending and interinstitutional comparisons.

Table 2 Patient demographics: neuro ICU, on ventilator

	Prospective
N	393
Male/female	198/195
Age (mean ± SD)	61.7 ± 15.7
Deaths (expected)	137 (132)
Mortality %; O:E	35 %; 1.12
All neuro ICU	
NHSN respiratory	58 (3 %)
NHSN CAUTI	107 (10 %)

NHSN National Healthcare Safety Network, *CAUTI* catheter-associated urinary tract infection

The major limitations we encountered were a lack of diagnostic specificity and of sufficiently detailed comparator data, making benchmarking challenging at best. It was only when we turned to the more specific Centers for Disease Control and Prevention (CDC)/National Healthcare Safety Network (NHSN) definitions and processes that we were able to measure our infection rates with sufficient specificity and compare rates in our institution to similar ones elsewhere. Although, as with any epidemiologic definition, the NHSN approach sacrifices some sensitivity, it is reasonably specific—although imperfect [9]—that notwithstanding the highly specific case definitions for catheter-associated urinary tract infections (CAUTIs) and ventilator-associated events (VAEs) and pneumonias, allowed us to identify areas in which we had the greatest opportunities for improvement, and then track the results of our interventions over time.

Methods

To better understand factors contributing to HAIs in our institution, we first retrospectively reviewed outcomes in all patients (a) aged 18 or older; (b) admitted to our neuro ICU; (c) between January 1, 2011 and May 31, 2014; (d) with primary neurologic diagnoses; and (e) who required intubation and ventilator support.

We reviewed the data regarding respiratory and urinary tract infections (UTIs) in this population, using NIM markers from 2011 to 2014 as a surrogate measure. This automated, algorithm-driven approach allows for identification of hospital-acquired infections without requiring systematic chart review [10, 11], and has been shown to be more accurate than administrative data. Case identification begins with microbiology laboratory findings; excludes (a) infections present on admission, (b) organisms usually present as a result of contamination, and (c) duplicate specimens; and has been validated particularly as a measure of urinary and pulmonary infections.

Beginning in January 2013, NHSN-defined CAUTIs, VAEs, and probable/possible ventilator-associated pneumonias (PVAPs) were tracked prospectively by the hospital's Infection Prevention nurses, using strict NHSN definitions. The current NHSN criteria for CAUTIs require a culture identifying no more than two different bacterial pathogens with a colony count of at least 100,000/ml [12] for at least one of the pathogens, in a patient with other symptoms of a UTI or fever, and a urinary catheter that has been in place for more than two calendar days (or was removed within a day prior to recognition of the infection). Prior to a 2015 definition update, cultures with nonbacterial pathogens were included as were colony counts $<100{,}000$. To assure consistency, we applied the 2015 criteria retrospectively to our CAUTI data from January 2013 onward, although we found this affected only a very small number of cases.

Under the current NHSN rubric [12, 13], VAEs are divided into *ventilator-associated conditions* (VACs), defined as a period of worsened oxygenation in a patient whose ventilatory status was previously stable; *infectious VAC* (IVAC), defined as a VAC with evidence of infection such as elevated white blood cell count or fever with implementation of antimicrobial therapy; and PVAP, defined as an IVAC with purulent sputum or compelling laboratory evidence of a respiratory pathogen.

As we reviewed different potential contributors to HAIs in our institution, we recognized that our patients require frequent transports from the neuro ICU to Radiology for neuroimaging. In our hospital, this requires transfer to a stretcher, transport of some distance including an elevator ride, and then transfer to and from the scanner table. Each step provides an opportunity for unintentional manipulation of the endotracheal tube or urinary catheter. Despite best efforts during transport, patients do not invariably have the head of the stretcher elevated optimally; and the height of the urinary catheter relative to the bladder can fluctuate. Therefore, we specifically tested whether there was a relationship between HAIs, as reflected in urinary and respiratory NIMs, and the frequency of transport in and out of the neuro ICU for CT scans, independent of the duration of intubation or ICU stay. We reviewed the number of scans each patient had during the period prior to their positive NIM, then stratified patients by number of days intubated and, for each duration, calculated the average number of CT scans among those patients who developed a NIM and those who did not (Fig. 1).

Since we had systematic NHSN data from 2013 onwards, and NIM data through December 2014, we were able to assess the relationship between these two quite different measures. From 2013 onward, we measured the impact of our interventions using NHSN-defined CAUTIs, VAEs, and PVAPs.

Interventions

In July 2014, we began an extensive review of our utilization of urinary catheters, including the indications for insertion and discontinuation [6], and the techniques used both to insert and maintain them. Since we were unable to identify specific contributory factors to our high rate of CAUTIs, we re-educated all caregivers in, and universally adopted, the Ann Arbor criteria for appropriateness of catheter placement and removal [14] and assured that daily rounds in the ICU always include questioning the continued need for every urinary catheter. We obtained new Foley kits (BARD® SURESTEP™) that simplified and helped standardize the steps involved in site preparation and catheter insertion, and we changed to routinely use 14 French catheters instead of 16. We found that some catheters were being inserted in the operating room or intervention suite. We changed the procedures at those sites to match those in use in the neuro ICU. We also trained personnel at those sites to remove catheters before sending the patient to the neuro ICU, unless there were a compelling need to continue them. All neuro ICU nursing staff were required to retrain in Foley catheter insertion, including both watching a video and then performing an observed simulation. All RNs and patient care technicians were retrained in soap and water perineum care, which was then done every (12-h) shift on all patients with indwelling catheters. Finally, processes were implemented to assure real-time feedback to the neuro ICU staff—including immediate notification and dissemination of all positive culture findings and maintaining a calendar in the neuro ICU indicating the number of days since the last CAUTI or other HAI. Following all requisite training, this process was fully implemented in August 2014.

In late December 2014, when our preliminary data suggested that patient transports out of the unit were contributing to the problem, and the impact of the enhanced Foley protocol was still suboptimal, we placed a mobile CT in the neuro ICU to perform routine head CTs at the bedside. By February 2015, this was being used routinely for approximately half of all neuro ICU head CTs, with Nursing and Radiology performing morning imaging rounds for 2 h early every day. Urgent or more complex scans, including CT angiography, continued to be performed in the imaging department; but these now represent a minority of all imaging in this population.

Statistical Analysis

For our initial exploratory analysis, we used hospital administrative data to collect demographic information as well as the numbers and timing of scans, combining this with the NIMs data. We used University HealthSystem

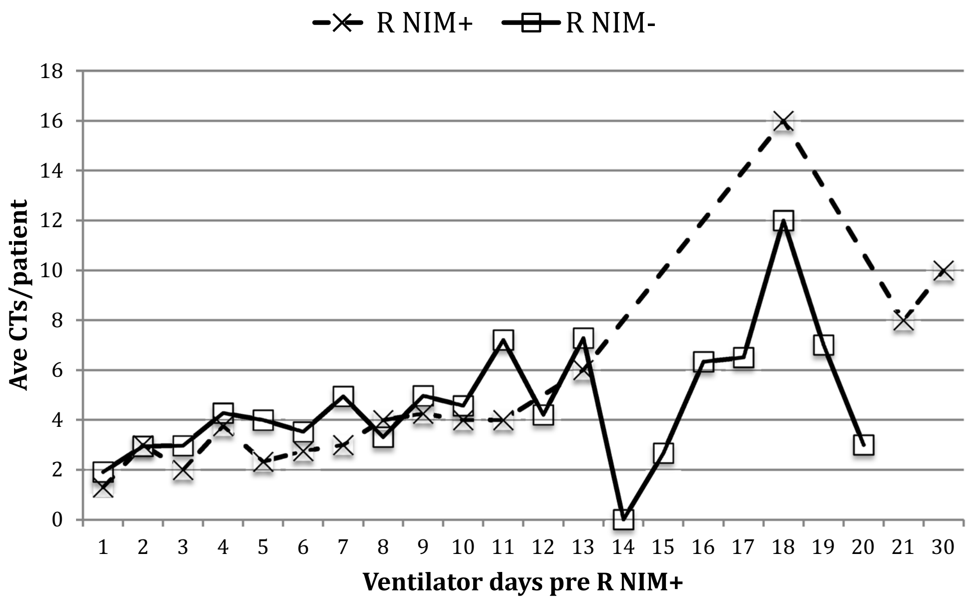

Fig. 1 *Horizontal axis* days on ventilator before positive respiratory NIM. *Vertical axis*, average # of CT scans/patient among patients with a + respiratory NIM versus those with negative respiratory NIM. While average number of CT's/patient was similar overall in the 2 groups (mean 3.3 vs. 3.5 scans/patient, positive NIM vs. negative), there is an apparent divergence after 2 weeks (mean number of CTs/patient 11.3 vs. 6.4, positive vs. negative)

Consortium (UHC now Vizient™) data for high-level external benchmarking. Descriptive statistics and comparisons were performed using StatPlus:mac Pro 6.0.3; (AnalystSoft Inc., Walnut, CA). Continuous variables were described as mean with 95 % confidence intervals. Statistical comparisons were performed using 2-tailed *t* tests (continuous variables) or chi-square tests [2] (dichotomous variables). Our prespecified primary outcome measures were numbers of CAUTIs, CAUTIs/1000 Foley days, and numbers of VAEs.

Results

From the outset, we recognized that the incidence of HAIs in our population was high, but we initially attributed this to our neuro ICU population being atypical. Although our risk-adjusted length of hospital stay (LOS) for these patients was indistinguishable from that in comparable UHC hospitals, our mean neuro ICU LOS was 1.3 days (29 %) longer; and our expected mortality for this population was 11.2 % compared to 7.7 % in the comparator group. Among patients with neuro ICU LOS of 2 or more days, 18 % of our patients had parenchymal hemorrhagic strokes (vs. 12 % in the comparison group), 17 % aneurysm repairs (vs. 11 %), 13 % medically managed ischemic strokes (vs. 12 %), and 4 % mechanical interventions for ischemic strokes (vs. 2 %). Taken together, this suggested our population was considerably more ill and at greater risk of all complications.

When we analyzed HAIs retrospectively, we found that, in the study period, 458 patients required ventilator support; 144 of these required intubation for 7 or more days. Eighty-four developed positive respiratory NIMs (18 %); on average, these patients underwent 3.5 head CTs prior to the NIM; and 108 developed positive urinary NIMs (23 %), with 3.9 CTs each on average prior to the NIM.

We reviewed the occurrence of positive respiratory and urinary NIMs in relation both to the duration of intubation and to the number of transports off the unit for CT scans. In exploratory univariate analyses, we found that the total number of scans performed during the hospitalization was significantly greater in patients who developed positive respiratory or urinary NIMs than in those who did not (Table 3; $p < 0.001$ for each). The average number of scans performed prior to the development of respiratory (3.5) and urinary (3.9) NIMs was greater than the total 3.4 (NS) and 3.3 ($p = 0.04$) number of scans, respectively, obtained throughout the entire hospitalization of patients who never developed respiratory and urinary NIMs.

Since this is potentially confounded by the fact that patients with positive NIMs had longer LOS and more prolonged intubation, we focused the analysis on patients who developed NIMs while still on the ventilator, stratifying patients by the number of days intubated—either in total without a NIM or preceding a respiratory NIM (Fig. 1). Overall, the difference in mean number of scans was not statistically significant. However, inspection of the distribution of numbers of scans suggests that while scan frequency was comparable for patients intubated up to 2 weeks, beyond this time, the number of scans in patients with positive NIMs was greater than that in those with negative ones, although the sample size was too small for this to be statistically significant ($p = 0.13$).

Table 3 Retrospective data analysis of neuro ICU patients requiring mechanical ventilation, admitted between January 2011 and May 2015

	Urinary NIMs			Respiratory NIMs		
	Positive	Negative		Positive	Negative	
#	108 (23 %)	352		84 (18 %)	376	
Age (mean, CI)	58.7 (58.6–61.8)	61.1 (59.4–62.9)	NS ($p = 0.19$)	58.7 (55.5–62.0)	61. 0 (59.2–62.7)	NS ($p = 0.26$)
NIMs(M/F)	31/76 (29 %)	189/173	0.0002 χ^2	37/47	179/197	NS $p = 0.56$
NHSN + (M/F)	9/26 (2 %)	207/218	0.009 χ^2	8/10	208/234	NS $p = 0.83$
LOS	28.1 (25.6–30.6)	12.0 (10.6–13.4)	<0.0001	32.3 (26.2–38.5)	13.1 (11.9–14.2)	<0.0001
Days pre NIM	9.7 (8.0–11.5)			9.4 (6.6–12.1)		
Vent days	7.9 (6.3–9.6)	5.4 (4.8–5.9)	0.0002	15.1 (12.9–17.2)	4.6 (4.1–5.1)	<0.0001
Observed mortality	12.9 % (2.8–14.7)	45.7 % (41.1–51.5)	<0.0001	39 % (29–50)	38 % (33–43)	NS $p = 0.80$
Mortality O:E	0.71	1.36		1.27	1.27	
# CTs	6.7 (5.8–7.6)	3.3 (3.0–3.5)	<0.0001	7.2 (6.0–8.3)	3.4 (3.1–3.7)	<0.0001
CTs pre NIM	3.9 (3.4–4.7)		0.04	3.5 (2.8–4.2)		NS

(Denominators slightly different between urinary and respiratory datasets due to incomplete data on some patients). Comparison by χ^2 for dichotomous variables, 2-tailed *t* test for continuous ones

NIM nosocomial infection marker, *NHSN* National Healthcare Safety Network, *LOS* length of hospital stay

Among patients for whom we had both NIM and NHSN data (2013 and 2014 data; 463 patients), urinary NIMs were positive in 108, versus 36 NHSN CAUTIs; respiratory NIMs were positive in 84, versus 19. Compared to NHSN-based diagnoses, urinary NIMs were 94 % sensitive and 83 % specific; respiratory 58 % and 84 %, respectively. CAUTIs, as measured by either urinary NIMS or NHSN criteria, were about three times as frequent among women as among men, a finding that was highly statistically significant (Table 3). In contrast, men and women were equally likely to have a positive respiratory NIM.

We then prospectively tracked NHSN data as we implemented our corrective actions (Fig. 2). In 2013–2014, we averaged 1.8 VAEs/month, a third of which were PVAPs, with 24 VAEs and 3 PVAPs in 2013 and 17 and 10, respectively, in 2014. In late December 2014, we placed the mobile CT in the neuro ICU and spent the next 8 weeks implementing protocols for its regular use. By mid-February, we were routinely performing half of all neuro ICU head CTs at the bedside, a proportion that has been maintained ever since. In January 2015, we had 4 VAEs including 1 PVAP; in February, we had 1 VAC. For the remainder of 2015, we had 10 additional VAEs, 3 of which were PVAPs (total for the year 15 VAEs, 4 PVAPs). We had no VAEs in 2 of the first 3 months in 2016, with 2 VACs and no PVAPs in the third. From January 2015 through March 2016, we had 6 months with zero VAEs, more than the total VAE-free months in the prior 2 years combined. Comparing the period from 2013 through January 2015 to that from February 2015 through March 2016, the number of VAEs/month decreased from 1.8 (95 % CI, 1.3 %–2.4 %) to 0.9 (95 % CI, 0.4 %–1.5 %) ($p = 0.035$, 2-tailed *t* test); the number of PVAPs/month declined by more than 50 %, from 0.56 (95 % CI, 0.2 %–0.9 %) to 0.21 (95 % CI, −0.03 % to 0.45 %; NS).

The August 2014 re-education program was followed by an immediate decline in Foley utilization but an increase in CAUTIs/1000 Foley days with no net change in CAUTIs/month. The monthly data (Fig. 3; Table 4) indicate an overall decline in CAUTIs starting in the first few months of 2015, following the introduction of the mobile CT. Overall (Table 4), the number of CAUTIs/month, and the rate per 1000 Foley days, decreased from a baseline of 2.4/month to 0.8/month ($p < 0.001$, 2-tailed *t* test) and 10.9 CAUTIs/1000 Foley days to 6.2 ($p = 0.04$, 2-tailed *t* test), the latter corresponding to a standardized infection ratio (SIR, NHSN; compared to all neurosurgical ICUs) of under 1.0. The number of Foley days/month decreased from 222 (95 % CI, 209.0 %–236.2 %) to 182 (95 % CI, 149.2 %–214.1 %) ($p = 0.006$, 2-tailed *t* test) for the period from Aug 2014 through January 2015, followed by a further reduction to 119 (95 % CI, 97.1 %–141.5 %) ($p < 0.003$, 2-tailed *t* test) compared to the prior 6 months. Together, these two effects resulted in an overall reduction in monthly CAUTIs by 2/3.

Discussion

Critically ill patients with severe central nervous system compromise, typically intubated with indwelling intravenous and urinary catheters, are at considerable risk of nosocomial infections. In this study, we retrospectively reviewed our experience with these HAIs, identified and implemented interventions, and prospectively assessed their impact. In the process, we assessed the relative

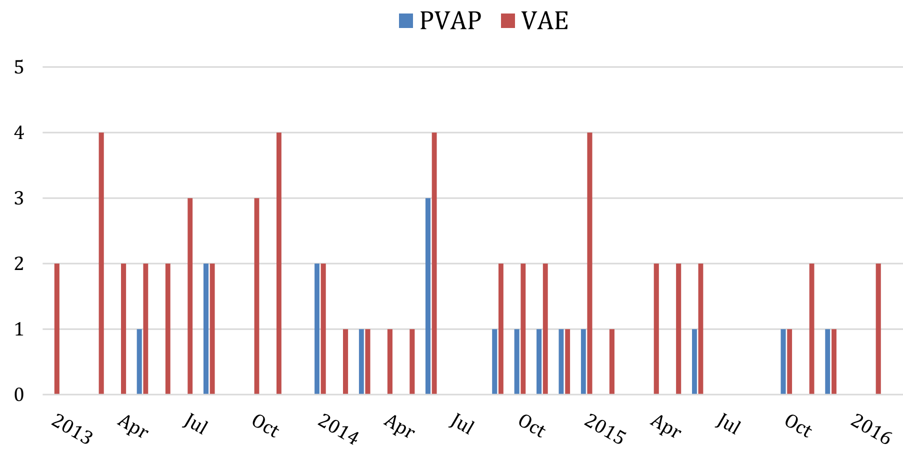

Fig. 2 Monthly NHSN VAEs and PVAPs (2015 definitions). Notably in 2013, we had 24 VAEs (3 PVAPs), 17 in 2014 (10 PVAPs), and 15 in 2015 (4 PVAPs). In Q1 2016, we had 2 VAEs but no PVAPs. *NHSN* National Healthcare Safety Network, *VAE* ventilator-associated event, *PVAP* probable/possible ventilator-associated pneumonia

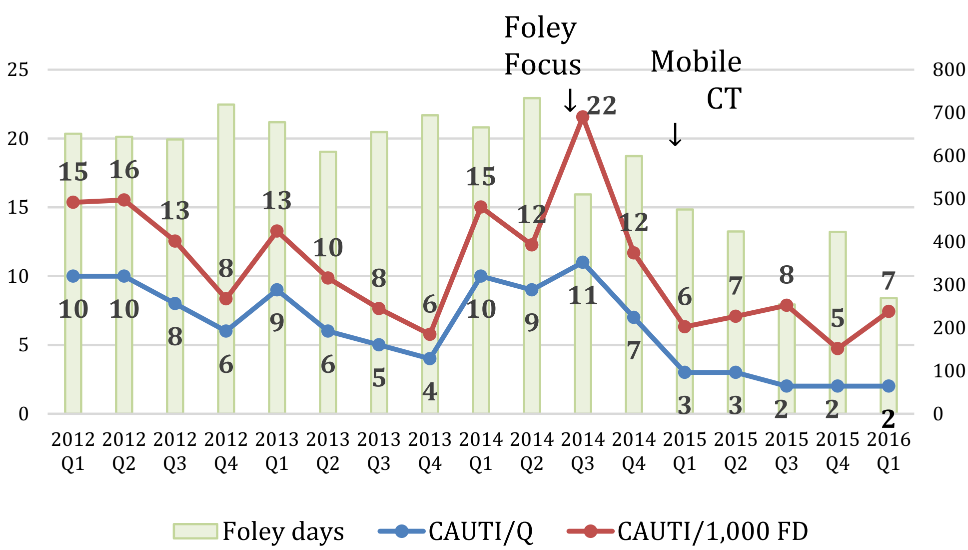

Fig. 3 Quarterly NHSN catheter-associated urinary tract infections, Foley days/quarter, and CAUTIs/1000 Foley days. The increase in CAUTIs in Q3 2014 was driven by a spike of 5 in September, the first month we fully implemented the new catheter care procedures. Prior to implementing this protocol, we averaged 3.2 CAUTIs monthly in 2014. For the remainder of 2014, we had 2 in each of October and November, 3 in December. In 2015, we had 2 in March and May, none in February, June, September, or December, 1 in each of the remaining months. There were 2 in January 2016; none in February or March. *NHSN* National Healthcare Safety Network, *CAUTI* catheter-associated urinary tract infection

sensitivity and specificity of two different objective measures of urinary and respiratory HAIs—NIMs and NHSN surveillance techniques.

To our knowledge, the relationship between HAIs and patient transports has not previously been investigated. Since patients requiring multiple CT scans are typically the same ones requiring prolonged intubation, it would be reasonable to assume that the relationship between number of scans and frequency of infections simply reflects the fact that both occur in patients requiring prolonged immobilization in the ICU. Because of the limitations of the administrative dataset that we needed to use in our preliminary analysis, our initial findings were ambiguous on this subject, but did suggest a potential association. On the one hand, patients with positive urinary or respiratory NIMs had, on average, twice as many scans as those who had negative NIMs ($p < 0.001$). On the other hand, they were on ventilators substantially longer. Focusing on the number of CTs obtained prior to the date of the positive NIM was confounded by an inability to determine the appropriate period of time to review in the comparison group of patients with negative NIMs, making a straightforward comparison challenging.

Table 4 NHSN infection rates

	PVAP/month		VAE/month
Jan 2013–Jan 2015	0.56 (0.22–0.89)		1.80 (1.25–2.35)
Feb 2015–Mar 2016	0.21 (−0.03–0.45)		0.93 (0.40–1.46)
t test	$p = 0.15$		$p = 0.035$
	CAUTIs/month	Foley days/m	CAUTI/1000 FD
Jan 2013–Jul 2014	2.42 (1.79–3.05)	222.6 (209.0–236.2)	10.85 (87.99–13.71)
Aug 2014–Jan-2015	2.67 (1.23–4.10)	181.7 (149.2–214.1)	15.2 (5.93–24.42)
Jan 2013–Jan 2015	*2.56 2.01–3.11*)	*212.8* (*199.0–225.6*)	*12.2*(*9.4–15.1*)
Feb 2015–Mar 2016	0.79 (0.32–1.25)	119.3 (97.1–141.5)	6.2 (2.5–9.9)
t test, period 1 vs. 2	0.69	0.006	0.18
t test period 2 vs. 3	0.001	0.003	0.02
t test period 1 vs. 3	0.003	<0.001	0.04
t test (1&2 vs. 3))	$p < 0.0001$	0.001	0.015

Baseline for VAE was January 2013 through January 2015, for CAUTIs from October 2013 to July 2014. Intermediate period is from August to January 2015. Current period for both is January 2015 through March 2016. Values are mean (95 % confidence interval). The numbers of VAEs and PVAPs decreased substantially following implementation of the mobile CT. The number of CAUTIs was impacted both by the 46 % decline in Foley days and the decrease in CAUTIs/Foley day. Much of the decline in the number of CAUTIs/1000 Foley days occurred following implementation of the mobile CT. Since there was no decrease in CAUTIs/1000 Foley days in the August 2014–January 2015 period, in the third line of CAUTI data, the entire period prior to January 2015 was pooled as the baseline

Given the ambiguous, if suggestive, nature of the preliminary data, and the fact that our HAI rates remained higher than we wished, we proceeded with two separate initiatives. First, we focused on decreasing CAUTIs, by implementing the Ann Arbor recommendations on urinary catheter utilization and decreasing Foley days by 46 % compared to baseline. At the same time, we retrained all involved in Foley catheter placement and maintenance. Several months later, we proceeded with implementation of bedside CT scans in the neuro ICU, primarily in the hope of decreasing VAEs. With this, the decreases in both VAEs—and CAUTIs have been both unambiguous and sustained.

We conclude that a multidisciplinary approach to care of the neurocritically ill patient—combining standard ventilator bundles with enhanced attention to urinary catheter maintenance and strict adherence to the Ann Arbor criteria limiting Foley catheter utilization as well as limiting avoidable transports of the patient in and out of the ICU—can result in a significant decrease in the prevalence of HAIs.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflicts of interest.

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