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Major article

Device-associated infection rates, device use, length of stay, and mortality in intensive care units of 4 Chinese hospitals: International Nosocomial Control Consortium findings

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Background: Little data exist on the burden of device-associated health care–associated infection (DA-HAI) in China. This study examined the DA-HAI rate and evaluated its association with device use (DU), length of stay (LOS), and mortality in intensive care units (ICUs) in 4 Chinese hospitals.

Methods: This was a prospective cohort surveillance study conducted in 7 ICUs in 4 hospitals. We applied International Nosocomial Control Consortium methods and Centers for Disease Control and Prevention (CDC)/National Health and Safety Network (NHSN) definitions to determine rates of central line–associated blood stream infection (CLABSI), ventilator-associated pneumonia (VAP), catheter-associated urinary tract infection (CAUTI), DU, crude extra length of hospital stay (LOS), and mortality.

Results: Between August 2008 and July 2010, there were a total of 2,631 admissions to the 7 ICUs in the study hospitals. The rate of VAP was 10.46/1,000 mechanical ventilator (MV)-days, the CLABSI rate was 7.66/1,000 central line (CL)-days, and the CAUTI rate was 1.29/1,000 urinary catheter (UC)-days. Pooled DU ratios were 0.43 for MV, 0.71 for CL, and 0.76 for UC. Crude extra LOS was 15 days for patients with CLABSI, 20.5 days for patients with VAP, and 27 days for patients with CAUTI. Crude extra mortality was 14% for patients with CLABSI, 22% for patients with VAP, and 43% for patients with CAUTI.

Conclusions: In the study ICUs, VAP and CLABSI rates were higher than CDC/NHSN's reported data, and LOS and mortality were increased. Compared with the CDC/NHSN and INICC data, the pooled DU ratio for MV was similar, and DU ratios for CL and UC use ratios were slightly higher.

Device-associated health care–acquired infections (DA-HAIs) in the intensive care unit (ICU)—particularly central line–associated bloodstream infection (CLABSI), ventilator-associated pneumonia (VAP), and catheter-associated urinary tract infection (CAUTI)—are known to pose a great threat to patient safety.[1] The adverse effects of DA-HAI—attributable mortality, prolonged length of hospital stay (LOS), extra hospital costs, and increased bacterial resistance—are more far-reaching in the developing world.[2] A report from the International Nosocomial Control Consortium (INICC) with data from 36 developing countries noted that although device use (DU) in ICUs in developing countries was similar to that reported for US ICUs at the Centers for Disease Control and Prevention's (CDC) National Healthcare Safety Network (NHSN), rates of DA-HAI were significantly higher in INICC hospitals.[3,4]

Systematic surveillance of DA-HAIs is essential to effectively address the burden of these infections.[5] In developing countries, accurate knowledge is often underestimated[2]; in China in

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particular, only scanty data on DA-HAI have been reported to date.[6] The INICC was established in 2002 with the aim of measuring, controlling, and reducing DA-HAIs and associated consequences through the analysis of surveillance and promotion of systematized programs. The INICC provides free surveillance training and tools to infection control practitioners (ICPs) worldwide.[7] The rationale behind this article is to help advance the knowledge of DA-HAIs in China by presenting a descriptive analysis of DA-HAI prevalence, extra LOS, mortality rates, and DU ratio in 7 ICUs from 4 INICC member hospitals in 4 Chinese cities.

METHODS

Study design and setting

We conducted a prospective, cohort study in 7 ICUs in 4 hospitals between August 2008 and July 2010. The participating hospitals are located in urban areas, in Shanghai (on China's eastern coast), Beijing (northeast), Xi'an (central), and Taiyuan (north). Distances between these 4 cities range from a minimum of 178 miles to a maximum of 773 miles. All 4 study hospitals are government-owned university teaching hospitals that provide tertiary care services. At each hospital, a microbiology laboratory provides in vitro susceptibility testing of clinical isolates using standardized methods, as described in the CDC/NHSN definitions. However, laboratory testing is not a common practice in China, and is frequently avoided for cultural reasons specific to China.[8]

On average, ICU nurse-to-patient staffing ratios are 1:1 during the day shift and 1:2 during the night shift. Physician-to-patient ratios in ICUs range from 1:2 during the day shift to 1:5 during the night shift. The average ICU cleaner-to-bed ratio is 1:10. ICPs at each hospital have a minimum of 1 year of experience in infection control.

Before the present study, no surveillance was performed in 5 of the 7 participating ICUs. A simple surveillance system was in place in the 2 ICUs in Shanghai, but this system did not analyze LOS, mortality, and many other outcomes included in the INICC surveillance. Infection control practices, such as hand hygiene and central line (CL) care monitoring, were not performed before the initiation of this study in the 7 participating ICUs, and intravenous infusions were (and still are) provided with open glass or semirigid containers.

The participating ICUs admitted patients according to the type of care needed, regardless of age. As a result, pediatric and adult patients were treated in the same ICU.

Study population

All patients admitted to one of the 7 study ICUs were included in this study. All were followed up until discharge.

Data collection and training

The INICC Chairman trained the ICPs in the INICC surveillance methodology. The ICPs at each hospital completed an INICC surveillance form for each patient admitted to the ICUs. Completed forms were sent to the INICC Headquarters Office in Buenos Aires for analysis.[7] Patient confidentiality was protected by codifying the recorded information, making it identifiable only to each hospital's ICP.[7] Each hospital's Institutional Review Board approved the study protocol.

INICC surveillance program

The INICC surveillance program includes outcome and process surveillance. Outcome surveillance included rates of DA-HAI per 1,000 device-days, DU ratio, crude extra LOS, and mortality during patients' stay in the ICUs. Demographic and DU data were collected prospectively. DA-HAI data were recorded based on the CDC/NHSN definitions.[8]

Outcome surveillance

DA-HAI rate calculation. Outcomes measured during the surveillance period included the incidence density rate of CLABSI (number of cases per 1,000 CL-days), CAUTI (number of cases per 1,000 urinary catheter [UC]-days), and VAP (number of cases per 1,000 mechanical ventilator [MV]-days). Rates of VAP, CLABSI, and CAUTI per 1,000 device-days were calculated by dividing the total number of DA-HAIs by the total number of specific device-days and multiplying the result by 1,000.[9]

INICC and CDC methodologies differ in how CL-days are calculated. According to the INICC methodology, CL-days are calculated for each CL is in situ, which are counted separately when calculating the time at risk. In contrast, in the CDC methodology, CL- days are calculated for each day that a patient has 1 or more CLs in place. Thus, if the CDC methodology is applied, a patient with 2 CLs in situ for 1 day will contribute 1 CL-day at risk, whereas if the INICC methodology is applied, the same patient will contribute 2 CL-days. Occasionally, this can lead to a CL DU ratio of >1 in ICUs in which patients routinely have more than 1 CL in place.

DU ratio calculation. DU ratios were calculated by dividing the total number of device-days by the total number of patient-days. Device-days are the total number of days of exposure to the device (CL, MV, or UC) for all of the patients in the selected population during the specified time period. Patient-days are the total number of days that patients are in the ICU during the specified time period.[9]

LOS and mortality calculations. LOS and mortality data were collected prospectively when comleting the daily INICC forms. The crude extra LOS is the difference between the LOS of patients with a DA-HAI and that of patients hospitalized in the ICU during the same period who did not acquire a DA-HAI.[7] Crude excess mortality was calculated as the difference between the crude overall case fatality of patients with a DA-HAI and the crude case fatality of patients hospitalized in the ICU during that period who did not acquire a DA-HAI.[7]

Process surveillance

Process surveillance included rates of hand hygiene (HH) compliance and CL care monitoring.

HH compliance. HH compliance by health care workers (HCWs) was determined by measuring the frequency on which HH is performed according to the World Health Organization (WHO) "Five Moments for Hand Hygiene."[10] Practices and contacts were monitored by the ICP's direct observation during randomly selected 1-hour observation periods, 3 times a week. Although HCWs know that HH practices are regularly monitored, they are not actually aware of the precise moment in which observations are occurring.[7]

CL care compliance. CL care compliance is monitored and recorded 5 days a week through completion of surveillance forms that evaluate HCWs' performance of infection control procedures. The ICP observing the activity in the ICU completes a standardized form containing the following data: total number of inserted CLs for each

Table 1
Demographic data of the patient population and device use by ICU

			Hospital 2		Hospital 3		Hospital 4	
	All	Hospital 1, medical cardiac	Medical-surgical	Medical-surgical	Medical-surgical	Neurologic	Medical cardiac	Surgical
Contribution to study								
Study period	8/08-7/10	8/09-7/10	8/09-6/10	7/09-6/10	7/09-6/10	7/09-6/10	8/08-7/09	8/08-7/09
ICU admissions during study period	2,631	157	294	277	155	113	889	746
Bed-days contributed	17,359	953	1,869	2,689	1,849	1,695	4,090	4,214
Hospital characteristics								
Hospital bed size		1,380	1,565		1,200		1,700	
ICP experience		1-3 years	18 years		17 years		20 years	
Patient characteristics								
Age, years, median (range)	60 (1-100)	62 (31-82)	64 (15-98)	55 (1-98)	58 (11-94)	63 (18-85)	57 (3-99)	62 (6-100)
Male sex, n (%)	1,721 (65)	108 (69)	189 (64)	173 (62)	95 (61)	71 (63)	563 (63)	513 (69)
APACHE score, median (range)	9 (0-54)	7 (1-16)	21 (0-51)	14 (0-43)	12 (0-46)	12 (0-42)	5 (0-54)	11 (2-37)
DU ratio								
CL	0.71 (0.70-0.73)	1.24 (1.17-1.31)	0.15 (0.13-0.16)	0.57 (0.54-0.6)	0.7 (0.66-0.74)	0.58 (0.55-0.62)	0.91 (0.88-0.94)	0.81 (0.78-0.84)
MV	0.43 (0.42-0.44)	0.5 (0.47-0.53)	0.13 (0.12-0.15)	0.47 (0.45-0.49)	0.49 (0.47-0.51)	0.23 (0.21-0.25)	0.4 (0.38-0.41)	0.61 (0.59-0.62)
UC	0.76 (0.75-0.77)	0.99 (0.98-0.99)	0.4 (0.38-0.42)	0.7 (0.68-0.71)	0.8 (0.78-0.82)	0.61 (0.59-0.64)	0.9 (0.89-0.91)	0.81 (0.8-0.83)

APACHE, Acute Physiology and Chronic Health Evaluation.

patient for the entire ICU; total number of dressings placed to protect the insertion site; total number of dressings, specifying the type of dressing (sterile gauze or transparent dressing) used to protect the insertion site; total number of dressings in proper condition, evaluating whether the dressing was clean and dry and correctly adhered to the insertion site; and total number of cases in which the dates of insertion were written in the administration set or the dressing.[7]

Validation

INICC surveillance forms include every clinical and microbiological criterion for each type of health care–associated infection. This information permits both internal (within the hospital) and external (at the INICC's central office) validation of the surveillance data. At the participating hospital, the ICP who reviews the data forms from the hospital's ICUs can verify that adequate criteria for infection were fulfilled in each case. Finally, original patient data forms can be further validated at the INICC's central office before data on the reported infection are entered into the INICC database.[11-16]

During this study, each recorded form was evaluated by the INICC Chairman for a possible DA-HAI, even if the patient report from the hospital did not state as such. The following criteria were used to identify suspected DA-HAI: presence of fever (temperature $\geq$38°C), any changes in antibiotic use (eg, new antibiotic added, change in dose), change of CL, low blood pressure (systolic $\leq$90 mm Hg), and any blood cultures obtained and whether or not cultures were positive for a microorganism. The INICC Chairman visited each ICU personally on 3 occasions to discuss these possibly adjudicated cases and review all medical records. This review of the surveillance data revealed that, 85 of the 171 DA-HAIs included in this report (48.5%) had not been initially reported as a DA-HAI by the hospital's Infection Control Team, but were later identified by the INICC as a possible DA-HAI.

Statistical analysis

Data entry and basic analyses were performed using EpiInfo version 6.04b (Centers for Disease Control and Prevention, Atlanta, GA). Further analyses were performed using Stata 11.1 (StataCorp, College Station, TX). The χ^2 test for dichotomous variables and the *t* test for continuous variables were used to analyze baseline differences among rates. Relative risk (RR) ratios, 95% confidence intervals (CIs), and *P* values were determined for all primary and secondary outcomes. A *P* value $<$.05 by a 2-sided test was considered to indicate statistical significance.

RESULTS

Participants

We analyzed data for 2,631 patients admitted to one of the participating ICUs during the study period. Patient demographic data by ICU are presented in Table 1.

Outcome surveillance

DA-HAI rates and DU ratios

DU was heterogeneous across ICUs, as shown in Table 1. The overall CLABSI rate was 7.66 per 1,000 CL-days, the VAP rate was 10.46 per 1,000 MV-days, and the CAUTI rate was 1.29/1,000 UC-days (Table 2).

Mortality and LOS

Across the whole study, 5.4% of the patients admitted died. Mortality was 18% in patients with CLABSI, 26% in those with VAP, 47% in those with CAUTI, and only 4% in patients without an HAI. Crude extra mortality was 14% in patients with CLABSI, 22% in those with VAP, and 43% in those with CAUTI. Mortality was much higher at the extremes of age and lower in the middle (17-75 years) age group.

The median LOS was 18 days in patients with CLABSI, 23.5 days in patients with VAP, 30 days in patients with CAUTI, and only 3 days in patients without an HAI. Crude extra LOS was 15 days in patients with CLABSI, 20.5 days in those with VAP, and 27 days in those with CAUTI.

As shown in Table 3, CLABSI and VAP rates and mortality increase as LOS increases. We found an increased CLABSI rate in patients with a CL in place and an ICU LOS of $\geq$6 days. Similarly, in patients with MV with an ICU LOS of $\geq$11 days, the rate of VAP increased along with increasing LOS. No association was seen

Table 2
Stratified mortality, LOS, and device-associated HCAI rate

	N	Mortality, n (%)	LOS, days, median (range)	CLABSI (laboratory-diagnosed), n (%)	CLABSI rate/1,000 CL-days (95% CI)	VAP, n	VAP rate/1,000 MV- days (95% CI)	CAUTI, n	CAUTI rate/1,000 UC-days (95% CI)
All	2,631	142 (5.4)	3 (1-231)	95 (64)	7.66 (4.41-15.45)	78	10.46 (5.5-19.4)	17	1.29 (0.73-2.35)
APACHE score									
1-10	1,396	27 (1.93)	3 (1-108)	37 (26)	7.18 (3.6-22.08)	18	8.7 (4.71-16.47)	6	1.16 (0.56-3.78)
11-20	644	51 (7.92)	4 (1-89)	36 (25)	9.04 (3.84-23.54)	35	11.67 (6.16-22.37)	3	.69 (0.24-2.3)
≥21	325	47 (14.46)	5 (1-99)	16 (9)	9.26 (5.97-16.16)	11	8.47 (4.95-14.52)	7	3.35 (1.6-8.26)
Missing	266	17		6		14		1	
LOS, days									
1-5	1,834	53 (2.89)	2	6 (1)	1.63 (0.62-6.54)	0	0 (0)	0	0 (0)
6-10	405	31 (7.65)	7	23 (16)	12.21 (3.89-57.17)	6	5.42 (.55-216.09)	2	1.01 (0.27-6.15)
≥11	392	58 (14.80)	18	66 (47)	9.65 (5.96-17.21)	72	14.42 (9.66-21.05)	15	2.05 (1.34-3.26)
ICU	2,631	142 (5.4)	3 (1-231)	95 (64)	7.66 (4.41-15.45)	78	10.46 (5.5-19.4)	17	1.29 (0.73-2.35)
Hospital 1, medical cardiac	157	3 (1.9)	5 (1-60)	4 (3)	3.38 (1.27-9.02)	5	10.5 (4.37-25.24)	0	0 (0)
Hospital 2, medical-surgical	294	29 (9.8)	4 (1-44)	3 (1)	11.03 (3.56-34.2)	6	24.19 (10.87-53.85)	2	2.66 (0.67-0.65)
Hospital 2, medical-surgical	277	38 (13.7)	6 (1-108)	8 (6)	5.23 (2.62-10.46)	26	20.7 (14.09-30.4)	4	2.13 (0.8-5.68)
Hospital 3, medical-surgical	155	23 (14.8)	7 (1-76)	14 (6)	10.84 (6.42-18.31)	9	9.97 (5.19-19.16)	4	2.69 (1.01-0.18)
Hospital 3, neurologic	113	4 (3.5)	10 (1-99)	4 (1)	4.05 (1.52-10.79)	7	18.13 (8.65-38.04)	1	.96 (0.14-6.83)
Hospital 4, medical cardiac	889	23 (2.6)	2 (1-91)	46 (37)	12.34 (9.24-16.47)	13	7.99 (4.64-13.75)	5	1.36 (0.57-3.27)
Hospital 4, surgical	746	22 (3.0)	3 (1-231)	16 (10)	4.7 (2.88-7.67)	12	4.69 (2.67-8.26)	1	.29 (0.04-2.07)

APACHE, Acute Physiology and Chronic Health Evaluation.

Table 3
HH compliance and CL care monitoring by ICU

	All	Hospital 1, medical cardiac	Hospital 2		Hospital 3		Hospital 4, medical cardiac
			Medical-surgical	Medical-surgical	Medical-surgical	Neurologic	
HH compliance, %	51	77	37	47	40	59	–
Date on the intravascular device administration set, %	95.6	–	95.2	93.7	99.7	100.0	100.0
Presence of sterile gauze, %	99.9	–	99.5	100.0	100.0	100.0	100.0
Sterile gauze in good condition, %	93.7	–	87.4	92.0	99.7	100.0	100.0

between increasing LOS and an increased CAUTI rate. The CAUTI rate climbed steadily with increasing LOS, but the data are sparse and the 95% CI is wide (Table 3).

Process surveillance

HH compliance

HH compliance was monitored in 6 of the 7 participating ICUs during the study period. In these 6 ICUs, overall HH compliance was 51% (95% CI, 48.5%-53.5%). The highest rate of HH compliance was 77%, and the lowest was 37% (Table 2).

CL care

CL care was monitored in 5 of the 7 participating ICUs. High compliance with CL care practices was seen; 96.4% of catheters had the insertion date included in the administration set, 99.9% of catheters had sterile gauze placed, and 93.7% of catheters were in good condition (Table 2).

DISCUSSION

DA-HAIs have long been a primary and serious cause of patient morbidity and attributable mortality in the developing countries. DA-HAIs also have been identified as a factor contributing to increasing ICU LOS and health care costs.[1,2] The overall CLABSI rate of 7.66/1,000 CL-days in the present study is similar to the pooled rate of 6.8/1,000 CL-days in ICUs from developing countries reported in the last INICC report, but more than 3-fold higher than the 2.0/1,000 CL-days in comparable US ICUs reported in the NHSN report.[3,4] Likewise, the overall rate of VAP in the present study was more than 3-fold higher than that in US ICUs (10.46 vs 3.3/1,000 MV-days), but lower than the 15.8/1,000 MV-days reported for INICC ICUs. In contrast, the overall CAUTI rate of 1.29/1,000 UC-days in our ICUs is significantly lower thatn the rate of 6.3/1,000 UC-days reported in INICC ICUs and the 3.3/1,000 UC-days reported in NSHN ICUs.[3,4]

The lower CAUTI rate found in the present study can be attributed to the rare use of urine cultures in patients with sepsis or suspected urinary tract infection in the study hospitals. Our high rates of CLABSI and VAP are likely related to the fact that China, like most limited-resource countries, does not have laws mandating hospital infection control programs or hospital accreditation. In particular, the high rate of CLABSI seen in these Chinese ICUs, as in other developing countries, might be related to the use of outdated technology, including open infusion systems. The use of open infusion systems (the types used in the study ICUs), which provide intravenous fluid in glass bottles or semirigid plastic containers, has been linked to a significantly increased risk of cryptogenic infusion-associated bloodstream infections. A meta-analysis of 4 studies by Maki et al[16,17] reported an overall 67% decrease in the incidence of CLABSI after switching from an open infusion system to a closed infusion system.

DU ratios varied significantly among the study ICUs. Of note, highly variable ratios were found not only for the same type of device, but also for the same type of ICU (medical-surgical). Compared with pooled DU ratios reported for ICUs in the INICC report and the NHSN report, CL and CU DU ratios were slightly higher and the MV DU ratio was similar in our study ICUs.[3,4]

We also found increasing CLABSI and VAP rates with increasing ICU LOS. Specifically, a CL in place and an ICU LOS of ≥6 days is associated with an increased the CLABSI rate, and use of an MV and an ICU LOS of ≥11 days is associated with an increased VAP rate.

Our descriptive data also revealed the highest mortality rates at the extremes of age. When associated with high severity of illness score, very young and very old age have been identified as risk factors for mortality related to DA-HAI.[18,19] In this respect, according to a literature review of studies on CLABSI in limited-resource countries by Rosenthal et al,[20] the incidence and mortality of CLABSI vary widely in developing countries.

Finally, although infection control practices regarding HH compliance and CL care were monitored in most of the participating ICUs, this type of surveillance was not part of routine and regular activities in the ICUs, but were implemented for the purpose of this study. This process surveillance revealed consistently high compliance with CL care, but widely variable compliance with HH in these ICUs.

Implementation of DA-HAI surveillance is the first step to reducing the risk of DA-HAIs in Chinese ICUs. Surveillance not only provides an accurate picture of the threatening situation posed by DA-HAIs, but also plays a fundamental role in promoting exemplary infection control practices in the institution in general. It is of primary importance that DA-HAI surveillance be implemented along with a multidimensional infection control approach that includes practice bundles, education, infection control monitoring, performance feedback, and feedback on DA-HAI rates and the consequences of elevated rates. This INICC multidimensional approach has been shown to successfully reduce VAP,[21-24] CLABSI,[11-13] and CAUTI[14,15] in various studies conducted at INICC member hospitals. Of particular note, the rate of VAP was effectively reduced in Chinese ICUs, from 24.1/1,000 MV-days in 2005 to 5.7/1,000 MV-days in 2009, after the implementation of a multidimensional infection control model.[22]

Our study has some methodological limitations. First, our findings cannot be generalized to all ICU patients in China. Second, the extent to which nonquantifiable interventions, such as education and training, were applied might have varied among the ICUs. Third, in China HCWs rarely obtain cultures from ICU patients, and laboratory results are almost always negative in the few cultures analyzed, likely resulting in underregistration of CAUTIs and CLABSIs. A change in ICU practices is needed, and microbiology laboratory practitioners should receive adequate training. That said, however, we are aware of the cultural factors that hinder wider implementation of invasive procedures, including obtaining cultures.

In conclusion, simple and inexpensive preventive strategies, proven effective in the INICC ICUs through the implementation of multifaceted infection control programs, can result in significant reductions in DA-HAI rates and wider acceptance of infection control programs in hospitals in China and worldwide. For this reason, the INICC network is open to collaborate for free with any hospital with the compelling need to significantly prevent, control, and reduce DA-HAIs and their adverse effects.

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