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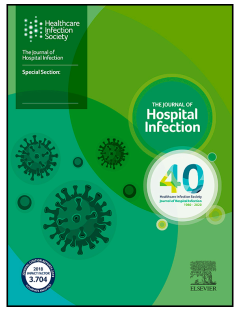

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Impact of the coronavirus disease 2019 pandemic on healthcare-associated infections at intensive care units in South Korea: Data from the Korean National Healthcare-Associated Infections Surveillance System (KONIS)

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ABSTRACT

Background: The coronavirus disease 2019 (COVID-19) pandemic has influenced hospital infection control practices. The impact of the COVID-19 pandemic on healthcare-associated infections (HAIs) in intensive care units (ICUs) was evaluated.

Methods: A retrospective analysis using data from the Korean National Healthcare-Associated Infections Surveillance System was conducted. Comparisons between incidence rates and microorganism distributions of bloodstream infections (BSIs), central line-associated bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), and ventilator-associated pneumonia (VAP) before and during the COVID-19 pandemic were performed according to hospital size.

Results: The incidence rate of BSI significantly decreased during the COVID-19 pandemic compared to the pre-COVID-19 period (1.38 vs. 1.23 per 10,000 patient-days, relative change -11.5%; P<0.001). The incidence rate of VAP (1.03 vs. 0.81 per 1,000 device-days, relative change -21.4%; P<0.001) significantly decreased during the COVID-19 pandemic compared to the pre-COVID-19 period, whereas that rates of CLABSIs (2.30 vs. 2.23 per 1,000 device-days; P=0.19) and CAUTIs (1.26 vs. 1.26 per 1,000 device-days; P=0.99) were similar between the two periods. The rates of BSIs and CLABSIs significantly increased during the COVID-19 pandemic compared to the pre-COVID-19 period in large-sized hospitals, whereas these rates significantly decreased in small to medium-sized hospitals. The rates of CAUTI and VAP significantly decreased in small-sized hospitals. There were no significant changing trends in the rates of multidrug-resistant pathogens isolated from patients with HAIs between the two periods.

Conclusion: The incidence rates of BSI and VAP in ICUs decreased during the COVID-19 pandemic compared to the pre-COVID-19 period. This decrease was mainly seen in small to medium-sized hospitals.

Keywords: Bloodstream infection; COVID-19; healthcare-associated infection; incidence; urinary tract infection; ventilator-associated pneumonia

INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic that began in December 2019 has influenced hospital infection control practices worldwide. There have been four waves of COVID-19, and a major epidemic with the Omicron variant is ongoing in South Korea (Supplementary figure 1). During the past two years, medical resources and infection control practices have been focused on the COVID-19 pandemic. In previous reports, COVID-19 was reported to be associated with increased rates of healthcare-associated infections (HAIs).[1-9] These results could be attributed to the neglect of conventional infection control practices, such as monitoring of handwashing activities and contact precautions for multidrug-resistant organisms. On the other hand, the COVID-19 pandemic has led to the strengthening of personal protective equipment usage in healthcare facilities. In this way, the COVID-19 pandemic has changed infection control measures. There was few studies investigating the impact of the COVID-19 pandemic on HAIs in intensive care units (ICUs) specifically, in which strict infection control is more essential than in general wards. The objective of this study was to evaluate the impact of the COVID-19 pandemic on HAIs in ICUs across the country, stratified by hospital size.

METHODS

Study population and design

A retrospective analysis using data from the Korean National Healthcare-Associated Infections Surveillance System (KONIS) was conducted. The KONIS has conducted nationwide prospective surveillance of HAIs and causative microorganisms in adult patients in ICUs in South Korea.[10] This surveillance system was launched in 2007 at each participating hospital. Each hospital's participation in the KONIS was voluntary, and the number of participating hospitals varied by year and quarter. These participating hospitals accounted for more than 70% of hospitals in South Korea, encompassing over 200 beds. The definitions and exclusions of HAIs were standardized according to the CDC/NHSN system.[11] The surveilled types of HAIs included BSIs, urinary tract infections, and pneumonia, for which the relevant devices (central line, urinary catheter, and ventilator) were also accessed. In addition, the data regarding the institutional characteristics of the participating hospitals were also collected from the KONIS. The data on the specific methods of the specimens were not included in the KONIS surveillance index.

In the study, comparisons of the incidence rates of bloodstream infections (BSIs), central line-associated bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), and ventilator-associated pneumonia (VAP) before (Jan 2018–Dec 2019) and during the COVID-19 pandemic (Jan 2020–Dec 2021) were performed according to hospital size. The microorganism distributions of CLABSIs, CAUTIs, and VAP were compared between the period before and during the COVID-19 pandemic. Additionally, the trends of rates of multidrug-resistant (MDR) pathogens before and during the COVID-19 pandemic were examined. The study was approved by the Kyung Hee University Hospital's Institutional Review Board.

Definitions

CLABSI was defined as a positive blood culture in a patient with a central line within the first 48 h preceding the development of a BSI that was not related to an infection at another site. CAUTI was defined as the occurrence of symptomatic bacteriuria or asymptomatic bacteremic UTI in a patient with a urinary catheter for at least two calendar days before the onset of a UTI. A case of asymptomatic bacteremia in a patient with a urinary catheter was excluded. VAP was defined as pneumonia meeting the clinical, radiological, and microbiological criteria used by the CDC/NHSN system in patients on ventilator support for at least two calendar days prior to VAP onset. The quarterly incidence rate of BSI was calculated as the number of BSIs per 10,000 patient-days for each quarter in the participating hospitals. The quarterly incidence rates of HAIs were calculated as the number of infections per 1,000 device-days for each quarter in the participating hospitals. The MDR pathogens included meticillin-resistant *Staphylococcus aureus*, vancomycin-resistant *Enterococcus faecalis*, vancomycin-resistant *E. faecium*, imipenem-resistant *Klebsiella pneumoniae*, imipenem-resistant *Pseudomonas aeruginosa*, and imipenem-resistant *Acinetobacter baumannii*.

Statistical analaysis

Statistical analyses were performed using R software 4.2.2. Categorical variables were compared using Pearson's χ^2 test or Fisher's exact test, as appropriate. Continuous variables were compared using the Mann–Whitney *U*-test. Rate differences were calculated using the test-based confidence intervals method, which compared the rates of BSIs and HAIs before and during the COVID-19 pandemic.[12] The Mann–Kendall trend test was used to analyze the trends in the rates of HAIs and MDR pathogens during the study periods[13]. Segmented regression analysis was used to access the breakpoints of the trends in the rates of HAIs and

MDR pathogens.[14] All statistical tests were two-tailed, and a value of $P \leq 0.05$ was considered to indicate statistical significance.

RESULTS

Incidence rates of HAIs before and during the COVID-19 pandemic according to hospital size

The characteristics of hospitals participating in KONIS from 2018 to 2021 are shown in Supplementary Table 1. The incidence rate of BSI significantly decreased during the COVID-19 pandemic compared to the pre-COVID-19 period (1.38 vs. 1.23 per 10,000 patient-days, relative change -11.5%; $P < 0.001$) [Table 1]. When analyzed according to hospital size, the rate of BSI significantly increased during the COVID-19 pandemic compared to the pre-COVID-19 period in large-sized hospitals (≥ 700 beds), whereas this rate significantly decreased in small to medium-sized hospitals (< 700 beds). Incidence rate of VAP (1.03 vs. 0.81 per 1,000 device-days, relative change -21.4%; $P < 0.001$) decreased significantly during the COVID-19 pandemic compared to the pre-COVID-19 period, whereas that rates of CLABSI (2.30 vs. 2.23 per 1,000 device-days; $P = 0.19$) and CAUTI (1.26 vs. 1.26 per 1,000 device-days; $P = 0.99$) were similar between the two periods. According to hospital size, the incidence rate per 1,000 device-days of CLABSI significantly increased during the COVID-19 pandemic compared to the pre-COVID-19 period in large-sized hospitals (700–899 beds), whereas this rate decreased in small to medium-sized hospitals (< 700 beds). The incidence rates per 1,000 device-days of CAUTI and VAP significantly decreased only in small-sized hospitals (< 500 beds).

Quarterly trends of the incidence rates of HAIs

The quarterly trends of the incidence rates of VAP ($P = 0.01$) decreased during the study periods (Figure 1). There was no significant changing trend in the rate of VAP between the pre-COVID-19 period (coefficient 0.01, $P = 0.63$) and during the COVID-19 pandemic (coefficient -0.01, $P = 0.49$) (Supplementary figure 2). The estimated breakpoint of the changing trend in the rate of VAP was in the second quarter of 2018 (pre-COVID-19 period). There were no significant changes in the quarterly of incidence rate trends of BSI, CLABSI and CAUTI. In the segmental analysis, the estimated breakpoint of the changing trend in the rate of BSI was in the fourth quarter of 2020 (during the COVID-19 pandemic). The incidence rate of BSI decreased from the pre-COVID-19 period until the fourth quarter of 2020 (coefficient -0.03, $P = 0.01$) and showed an increasing trend after that, although significantly insignificant (coefficient 0.03, $P = 0.56$). There was a changing trend in the rate of CLABSI in the pre-COVID-19 period (coefficient -0.03, $P = 0.32$) and during the COVID-19 pandemic (coefficient 0.05, $P = 0.12$); however, this result was not statistically significant in the segmental analysis. When analyzed according to hospital size, the quarterly trend of the rate of BSI significantly increased in large-sized hospitals (≥ 700 beds), whereas this rate decreased in small to medium-sized hospitals (< 700 beds) (Supplementary figure 3). The quarterly trend of the rate of CLABSI significantly increased in large-sized hospitals (700–899 beds), whereas this rate decreased in medium-sized hospitals (500–699 beds). In the segmental analysis, the rate of CLABSI incidence changed from decreasing to increasing during the COVID-19 pandemic in small to medium-sized hospitals (< 500 beds) (data not shown). Meanwhile, the quarterly trends of the rates of CAUTI and VAP decreased only in small-sized hospitals (200–499 beds). In the segmental analysis, the incidence rates of CAUTI and VAP decreased from the pre-COVID-19 period in small-sized hospitals (200–499 beds) (data not shown).

Distribution of microorganisms in HAIs

The distribution of microorganisms in HAIs was shown in Table 2. Regarding CLABSIs, the pathogen rates of *Staphylococcus aureus* and *Streptococcus* species decreased during the COVID-19 pandemic compared to the pre-COVID-19 period, whereas that of *Klebsiella* *pneumoniae* increased. For CAUTIs, the pathogen rate of *Enterococcus* species decreased during the COVID-19 pandemic compared to the pre-COVID-19 period. For VAP, the pathogen rate of *Acinetobacter* species deceased during the COVID-19 pandemic compared to the pre-COVID-19 period, whereas that of *Stenotrophomonas maltophilia* increased.

The quarterly trends of the rates of MDR pathogens isolated from patients with HAIs were shown in Figure 2. The trends of the isolation rates of imipenem-resistant *K. pneumoniae* ($P < 0.001$) and imipenem-resistant *P. aeruginosa* ($P = 0.04$) increased during the study period. In the segmented regression analysis, a significant increasing trend was observed for the rate of imipenem-resistant *K. pneumoniae*, with an increase observed in the pre-COVID-19 pandemic period (coefficient 1.78, $P = 0.003$). There was no significant changing trend in the rate of imipenem-resistant *K. pneumoniae* during the COVID-19 pandemic (coefficient 1.26, $P = 0.08$). According to the segmented regression analysis, the estimated breakpoint of the changing trend in the isolation rate of imipenem-resistant *P. aerugionsa* was in the second quarter of 2018 (pre-COVID-19 pandemic). There was no significant changing trend in the rate of imipenem-resistant *P. aerugionsa* in the pre-COVID-19 period (coefficient 0.23, $P = 0.79$) and nor during the COVID-19 pandemic (coefficient 1.43, $P = 0.21$).

DISCUSSION

This study identified that the incidence rates of BSI and VAP decreased during the COVID-19 pandemic compared to the pre-COVID-19 period. This result was mainly observed in small to medium-sized hospitals. In the segmental analysis, there was a change in the trend of the rates of CLABSI from decreasing to increasing during the COVID-19 pandemic in small to medium-sized hospitals. In addition, the trends in the isolation rates of imipenem-resistant *K. pneumoniae* and imipenem-resistant *P. aerugionsa* increased during the study periods. However, there were no significant changing trends in the rates of multidrug-resistant pathogens isolated from patients with HAIs between the two periods.

There is controversy regarding the clinical impact of the COVID-19 pandemic on the incidence of HAIs. *Baker* et al. reported that the rates of CLABSI and CAUTI increased as the COVID-19 burden increased in 148 healthcare-affiliated hospitals.[1] In addition, the incidence rates of multidrug-resistant pathogens, such as meticillin-resistant *S. aureus*, vancomycin-resistant *Enterococcus* spp. and Gram-negative bacteria, were significantly associated with COVID-19 surges. These findings were comparable irrespective of hospital size. In a different study, Weiner-Lastinger *et al*. identified that significant increases in the national standardized infection ratios (SIRs) for CLABSI, CAUTI, ventilator-associated event (VAE) were observed during the COVID-19 pandemic.[5] In another study, Patel *et al*. reported a 28% increase in the national SIR for CLABSI in 2020 compared to that in 2019.[4] Notably, critical care units exhibited the greatest percentage increase in SIR, and all hospitals, regardless of bed size, demonstrated an increase in SIR. LeRose *et al*. reported that significant increases in CLABSIs, blood culture contamination rates, and lengths of hospital stays during the COVID-19 pandemic were observed.[3] In addition, other studies have reported that the COVID-19 pandemic has contributed to an increase of HAIs.[2,15] These studies explained that infection control measures focused on the COVID-19 pandemic resulted in increased HAI rates. In contrast, Wee *et al*. reported that the enhanced infection prevention and control measures put in place during COVID-19 pandemic led to a decrease in the rates of MRSA acquisition, CLABSI, and hospital-acquired respiratory viral infection,[16] noting that there was no increase in the rates of carbapenemase-producing Enterobacterales acquisition (CP-CRE), CAUTI, and VAP. The decrease in the rates of CLABSI and hospital-acquired respiratory viral infections may be related to the increased use of personal protective equipment due to the COVID-19 pandemic. However, this decrease was limited to CLABSIs and was not observed for CAUTIs and VAP. The studies using national surveillance data conducted in ICUs of each country also showed different results. In a study conducted in the Netherlands, the incidence rates of VAP and CLABSI increased during the COVID-19 pandemic,[9] and a study conducted in France also reported an increase in VAP and BSI during the pandemic.[8] On the other hand, in a study conducted in ICUs in Germany, it was reported that the rate of CLABSI did not increase during the COVID-19 pandemic, and the rate of CAUTI decreased.[7]

In this study, the impact of the COVID-19 pandemic on HAI rates differed by hospital size and the type of infection. For instance, the rate of BSI decreased in ICUs in South Korea during the COVID-19 pandemic, which may have been a continuous trend prior to the COVID-19 pandemic in small to medium-sized hospitals. Conversely, the rates of BSI and CLABSI tended to increase during the COVID-19 pandemic in large-sized hospitals. According to the segmented regression analysis in this study, the rate of CLABSI demonstrated an increasing trend during the COVID-19 pandemic in small to medium-sized hospitals, despite the fact that CLABSI showed a decreasing trend during the pre-COVID-19 period. The increase in the rate of CLABSI may be attributed to inadequate adherence to the infection control measures that were focused on the COVID-19 pandemic. In addition, the decrease in the rate of VAP observed in small to medium-sized hospitals was presumed to be due to the overall decreasing trends observed during the study period, as determined through segmented regression analysis. In terms of CAUTI, the incidence rate decreased in small-sized hospitals, a decreasing trend from the pre-COVID-19 period. There was no apparent influence of the COVID-19 pandemic on the incidence rates of VAP and CAUTI. This study is the first large-scale investigation to evaluate the impact of the COVID-19 pandemic on HAI rates in ICUs in South Korea. One of the strengths of the study is that it analyzed the changes in rates of HAIs according to hospital size.

This study has a few potential limitations. Firstly, analyzing the cause of changes in HAIs was difficult due to the absence of data on infection control measures. The changes in infection control practices in each hospital that participated in KONIS could not be determined because this data were not collected in KONIS. In addition, it was also challenging to analyze the impact of the potential shifts in patient populations resulting from COVID-19 patient management in individual hospitals. The data on the characteristics of patients admitted to the ICU, including age, sex, and comorbidities, could not be accessed in the KONIS surveillance index. However, admission to the ICU due to COVID-19 infection at most hospitals participating in KONIS would have been limited, except for cases of COVID-19 infection occurring during hospitalization, because the patients with severe COVID-19 infection have been exclusively admitted to the COVID-19–dedicated ICU due to South Korea’s national policy. In addition, the cases in which COVID-19 pneumonia persisted were excluded from KONIS data due to previous pneumonia. Therefore, it was assumed that the changes in patient characteristics between the pre-COVID-19 period and the COVID-19 pandemic were minor. Secondly, the study included only ICU data, making it difficult to extrapolate the findings of this study to general wards. Additional studies are needed to establish the impact of the COVID-19 pandemic on HAI rates in general wards. Thirdly, it was not possible to demonstrate changes in HAI rates using a standardized index, such as the standardized infection ratio (SIR)[4], as the KONIS dataset has not yet been standardized. In this regard, these results should be interpreted cautiously. Fourthly, this study does not reflect the impact of the ongoing Omicron epidemic in South Korea in 2022. Despite these limitations, this study may provide data regarding the changes in HAI incidence rates during the COVID-19 pandemic in South Korea.

In conclusion, the rates of BSI and VAP decreased in ICUs in South Korea during the COVID-19 pandemic. This result seems to be a continuous trend that existed before the COVID-19 pandemic in small to medium-sized hospitals. In large-sized hospitals, the incidence rates of BSI and CLABSI tended to increase during the COVID-19 pandemic. Therefore, continuous monitoring of HAI rates and the promotion of interventions are necessary to prevent an increase in HAIs, and attention should be paid to infection control measures in the context of the ongoing COVID-19 pandemic.

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Conflict of Interest

The authors report no conflict of interest.

AUTHOR CONTRIBUTIONS

YM Lee, KH Park, and MS Lee designed this study. YM Lee, EJ KIM, and MS Lee collected the data. YM Lee, DY Kim, and KH Park processed the data. YM Lee and MS Lee wrote the manuscript. YM Lee and MS Lee drafted the figure. All authors read and approved the final manuscript.

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Table 1. Incidence of healthcare-associated infections before and during the COVID-19 pandemic.

Variable	Pre-COVID-19 period					COVID-19 pandemic period					Relative change (%)	*P* value
	Number of events	Device days	Rate per 1,000 device days	Patient days	Rate per 10,000 patient days	Number of events	Device days	Rate per 1,000 device days	Patient days	Rate per 10,000 patient days		
All												
BSI	4,179	-	-	3,023,644	1.38	4,061	-	-	3,309,552	1.23	-11.5	<0.001
CLABSI	3,533	1,536,627	2.30	-	-	3,537	1,587,389	2.23	-	-	-3.0	0.19
CAUTI	3,242	2,580,117	1.26	-	-	3,085	2,455,660	1.26	-	-	0	0.99
VAP	1,091	1,061,341	1.03	-	-	794	985,886	0.81	-	-	-21.4	<0.001
> 900 beds (n = 25–27)												
BSI	1,018	-	-	584,934	1.74	1,020	-	-	518,832	1.97	12.4	0.01
CLABSI	894	374,317	2.39	-	-	944	371,856	2.54	-	-	6.3	0.46
CAUTI	643	501,139	1.28	-	-	599	458,242	1.31	-	-	2.3	0.74
VAP	292	288,773	1.01	-	-	244	269,435	0.91	-	-	-9.9	0.20
700–899 beds (n = 30–33)												
BSI	1,309	-	-	713,065	1.84	1,353			625,883	2.16	16.0	<0.001
CLABSI	1,143	405,461	2.82	-	-	1,154	374,395	3.08	-	-	9.2	0.03
CAUTI	866	560,130	1.55	-	-	836	530,876	1.57	-	-	1.3	0.70
VAP	301	303,639	0.99	-	-	230	256,226	0.90	-	-	-9.1	0.25
500–699 beds (n = 33–36)												
BSI	1,085	-	-	601,751	1.80	952			802,806	1.19	-40.8	<0.001
CLABSI	885	314,315	2.82	-	-	826	337,665	2.45	-	-	-13.1	<0.001
CAUTI	743	523,107	1.42	-	-	726	501,512	1.45	-	-	2.1	0.72
VAP	202	224,263	0.90	-	-	162	213,822	0.76	-	-	-15.6	0.10
200–499 beds (n =123–166)												
BSI	767	-	-	1,123,894	0.68	736	-	-	1,362,031	0.54	-23.0	<0.001
CLABSI	611	442,534	1.38	-	-	613	503,473	1.22	-	-	-11.6	0.03

CAUTI	990	927,922	1.07	-	-	924	965,030	0.96	-	-	-10.3	0.02
VAP	296	244,666	1.21	-	-	158	246,403	0.64	-	-	-47.1	<0.001

BSI, bloodstream infection; CLABSI, central line-associated bloodstream infection; CAUTI, catheter-associated urinary tract infection; VAP, ventilator-associated pneumonia

Table 2. Incidence of hospital-acquired infections according to microorganism before and during the COVID-19 pandemic.

Variable	**Pre-COVID-19 period** n (%)	**COVID-19 pandemic period** n (%)	***P* value**
CLABSI	3820	4002	
Gram-positive cocci			
Staphylococcus aureus	389 (10.2)	291 (7.3)	<0.001
CoNS	414 (10.8)	450 (11.2)	0.57
Streptococcus species	8 (0.2)	25 (0.6)	0.01
Enterococcus species	876 (22.9)	924 (23.1)	0.89
Gram-negative bacteria			
Escherichis coli	106 (2.8)	98 (2.4)	0.40
Klebsiella pneumoniae	233 (6.1)	316 (7.9)	0.002
Acinetobacter species	523 (13.7)	518 (12.9)	0.35
Pseudomonas species	104 (2.7)	137 (3.4)	0.08
Candida species	685 (17.9)	708 (17.7)	0.80
CAUTI	3391	3371	
Gram-positive cocci			
Enterococcus species	1219 (35.9)	1126 (33.4)	0.03
Gram-negative bacteria			
Escherichis coli	690 (20.3)	679 (20.1)	0.86
Klebsiella pneumoniae	352 (10.4)	402 (11.9)	0.048
Acinetobacter species	194 (5.7)	173 (5.1)	0.31
Pseudomonas aeruginosa	322 (9.5)	318 (9.4)	0.96
VAP	733	576	
Gram-positive cocci			
Staphylococcus aureus	115 (15.7)	80 (13.9)	0.41
Streptococcus pneumoniae	2 (0.3)	1 (0.2)	>0.99
Gram-negative bacteria			
Escherichis coli	17 (2.3)	14 (2.4)	0.96
Klebsiella pneumoniae	104 (14.2)	87 (15.1)	0.70
Acinetobacter species	281 (38.3)	178 (30.9)	0.01
Pseudomonas species	100 (13.6)	80 (13.9)	0.96

Stenotrophomons maltophilia	23 (3.1)	36 (6.3)	0.01

CLABSI, central line-associated bloodstream infection; CAUTI, catheter-associated urinary tract infection; VAP, ventilator-associated pneumonia; CoNS, coagulase-negative *Staphylococcus*

Figure 1. Quarterly trends of the incidence rate of healthcare-associated infections. BSI, bloodstream infection; CLABSI, central line-associated bloodstream infection; CAUTI, catheter-associated urinary tract infection; VAP, ventilator-associated pneumonia.

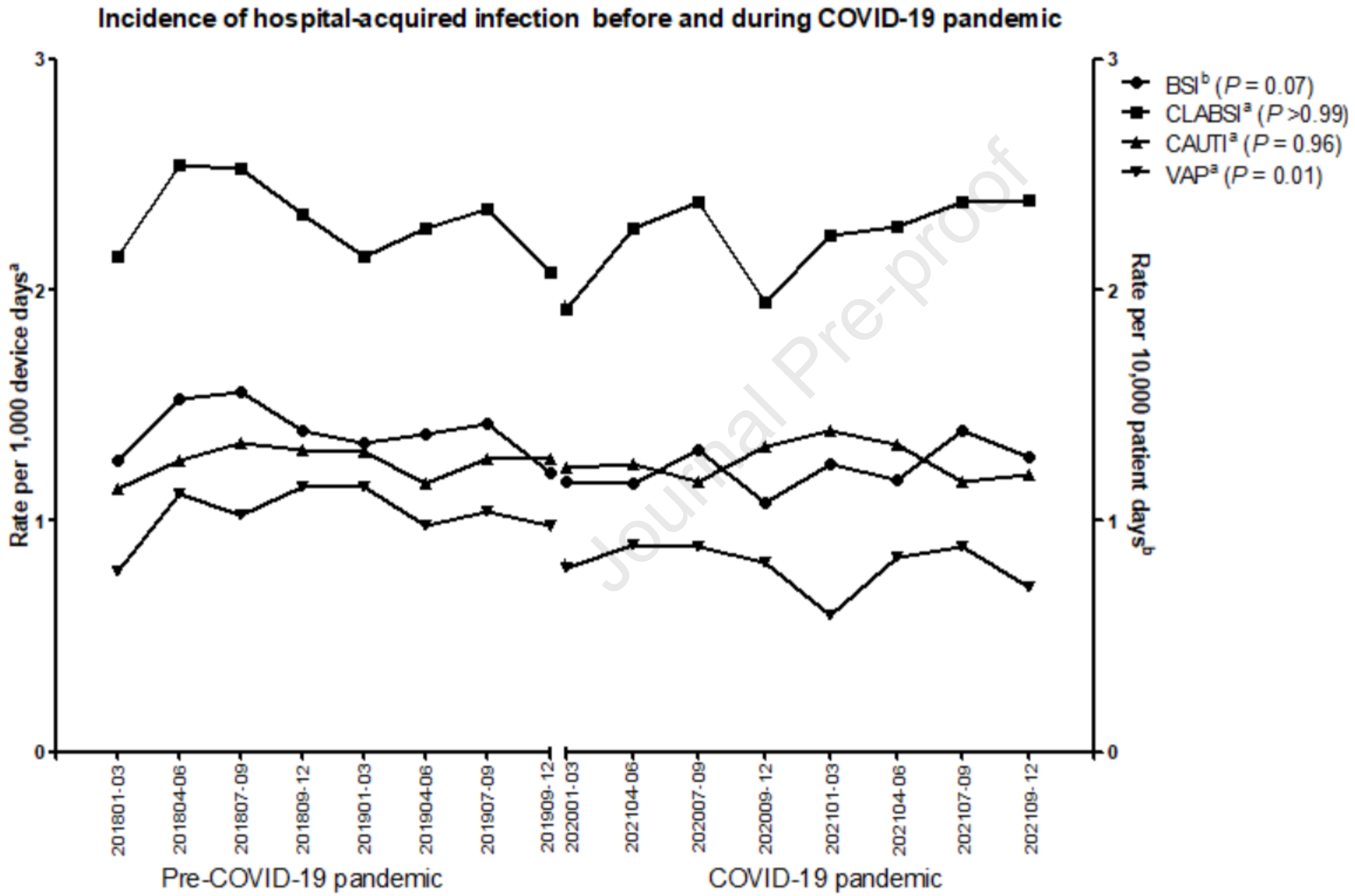
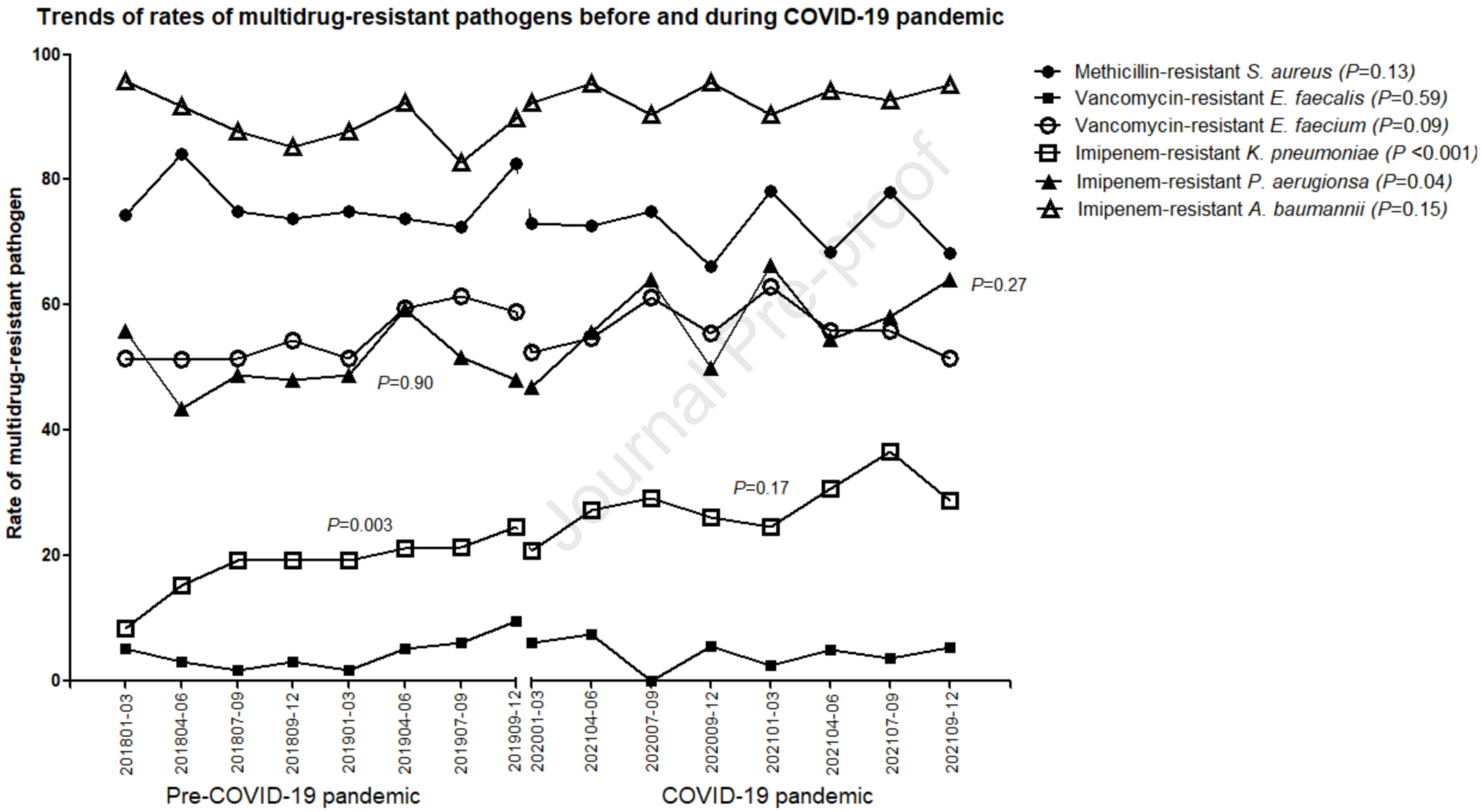


Figure 2. Quarterly trends of the incidence rate of multidrug-resistant pathogens isolated from patients with hospital-acquired infections.



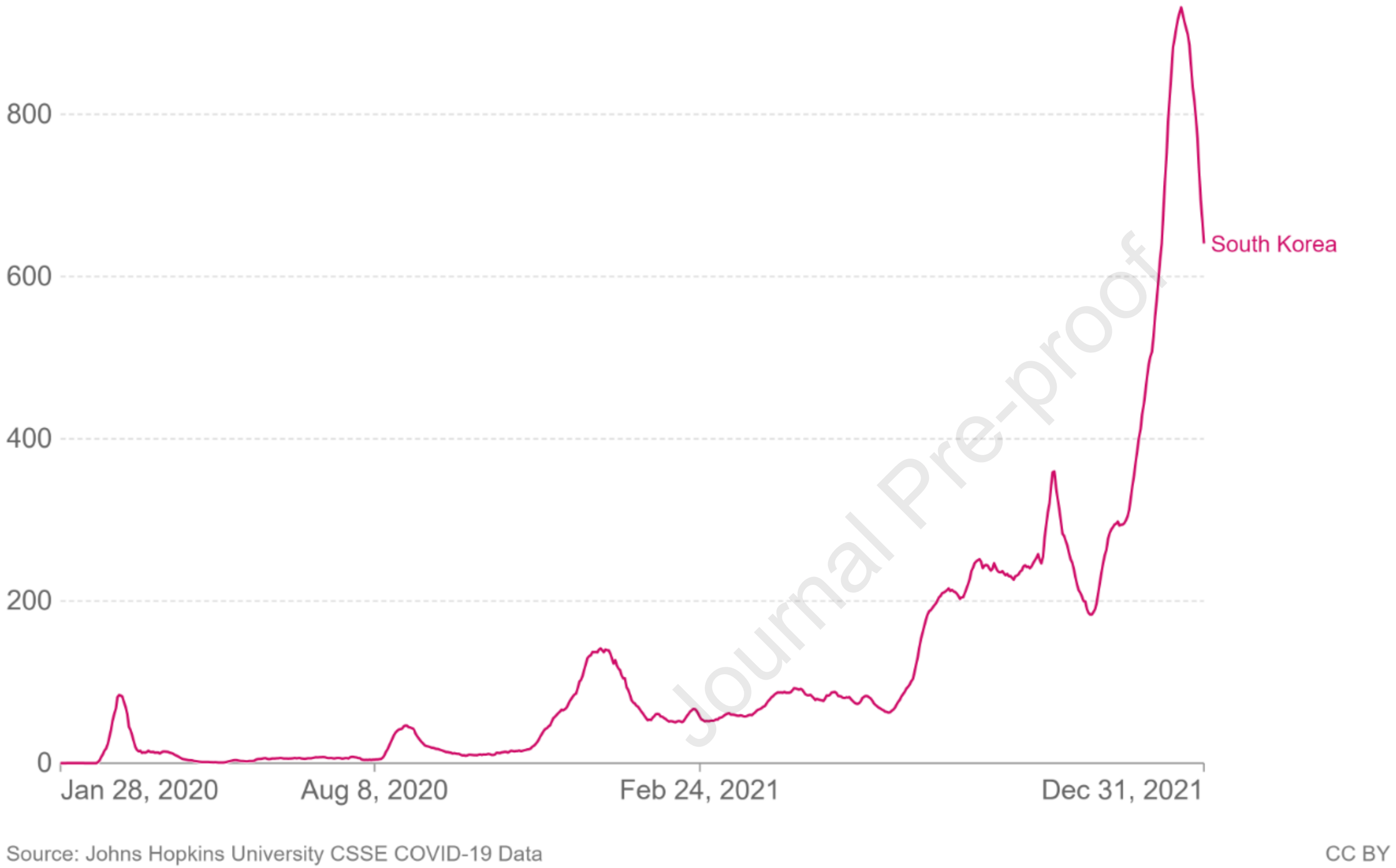
Supplementary table 1. Characteristics of hospitals participating in Korean National Healthcare-Associated Infections Surveillance System (KONIS) from 2018 to 2021.

Variables	Pre-COVID-19		COVID-19 pandemic	
	2018	2019	2020	2021
Characteristics of hospitals				
Total no. of hospitals	227	258	259	248
No. of major teaching hospitals	78 (34.4)	74 (28.7)	77 (29.7)	76 (30.7)
No. of private hospitals	172 (75.8)	197 (76.4)	195 (75.3)	199 (80.2)
Average no. of beds	531	500	499	514
Beds size				
≥ 900	27 (11.9)	26 (10.1)	27 (10.4)	26 (10.5)
700-899	31 (13.7)	32 (12.4)	30 (11.6)	31 (12.5)
500-699	34 (15.0)	33 (12.8)	34 (13.1)	36 (14.5)
300-499	62 (27.3)	67 (26.0)	68 (26.3)	67 (27.0)
200-299	73 (32.2)	100 (38.8)	100 (38.6)	88 (35.5)
Hospitals with special ward				
Solid organ transplantation	20 (8.8)	16 (6.2)	15 (5.8)	16 (6.5)
Hemodialysis	203 (89.4)	227 (88.0)	232 (89.6)	228 (91.9)
Infectious Diseases Physician per hospital	1.1	0.8	0.9	0.9
Infection Control Nurse per hospital	3.8	3.6	3.7	3.8
Infection Control Professional per hospital	2.8	2.4	2.5	2.6
Beds per Infectious Diseases Physician	472	603	554	544
Beds per Infection Control Nurse	142	140	134	134
Beds per Infection Control Professional	193	209	197	196

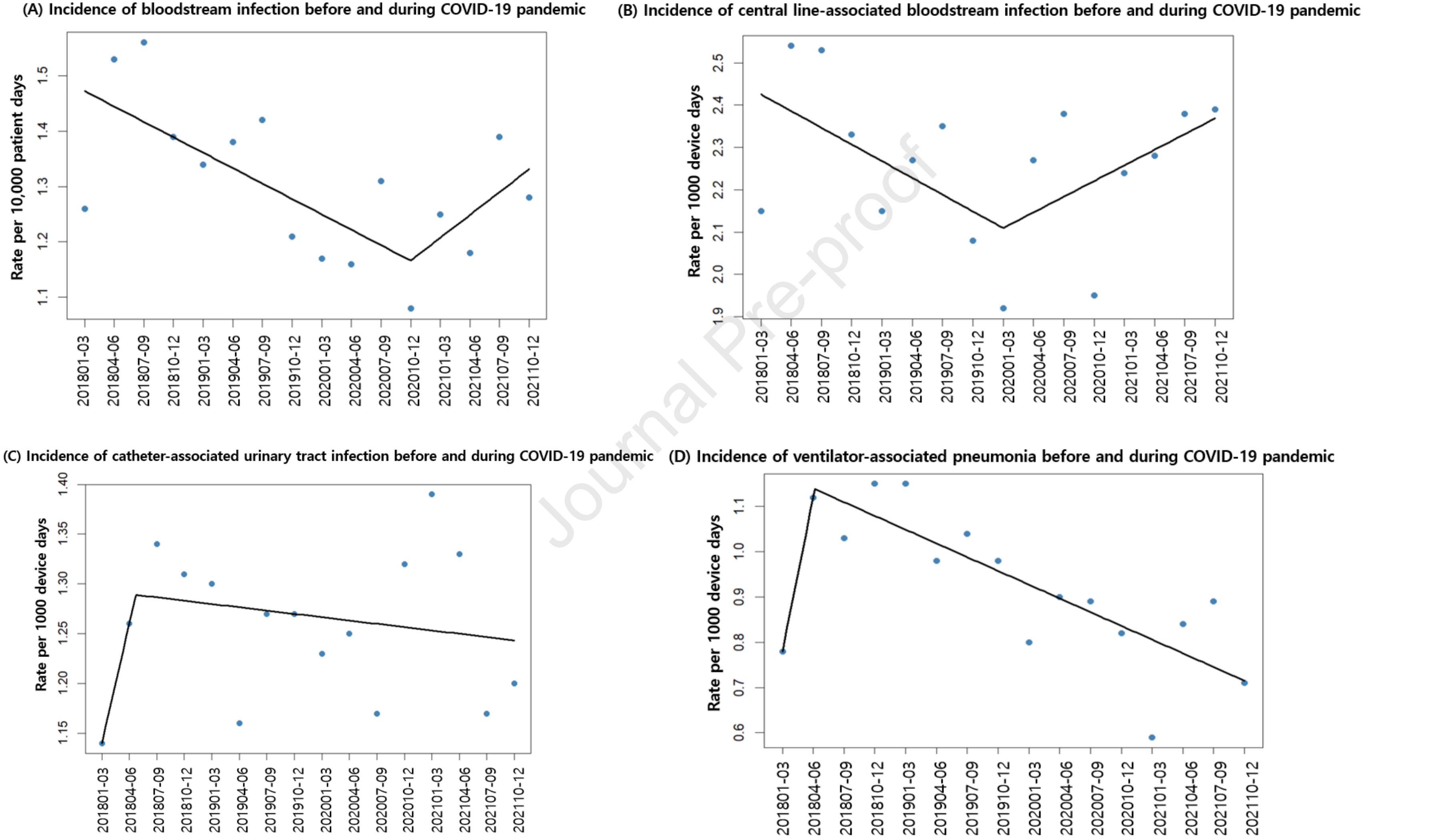
Composition of intensive care units (ICUs)				
Total no. of ICUs	320	346	340	320
Medical ICU (MICU)	93 (29.1)	98 (28.3)	94 (27.7)	82 (25.6)
Medical combined ICU (MCICU)	129 (40.3)	148 (42.8)	153 (45.0)	147 (45.9)
Surgical combined ICU (SCICU)	43 (13.4)	47 (13.6)	43 (12.7)	41 (12.8)
Surgical ICU (SICU)	25 (7.8)	25 (7.2)	24 (7.1)	24 (7.5)
Neurosurgical ICU (NSICU)	30 (9.4)	28 (8.1)	26 (7.7)	26 (8.1)

Data are presented as no. (%) of patients, unless otherwise indicated.

Supplementary figure 1. Weekly confirmed COVID-19 cases per million people in South Korea.



Supplementary figure 2. Quarterly trends of the incidence rate of healthcare-associated infections according to segmented regression analysis. (A) Bloodstream infection, (B) central line-associated bloodstream infection, (C) catheter-associated urinary tract infection, (D) ventilator-associated pneumonia.



Supplementary figure 3. Quarterly trends of the incidence rate of healthcare-associated infections according to hospital scale. (A) > 900 beds, (B) 700–899 beds, (C) 500–699 beds, (D) 200–499 beds. BSI, bloodstream infection; CLABSI, central line-associated bloodstream infection; CAUTI, catheter-associated urinary tract infection; VAP, ventilator-associated pneumonia.