Bed occupancy and nosocomial infections in the intensive care unit: A retrospective observational study in a tertiary hospital

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Background. Healthcare-associated infections (HAI) are a major problem globally, contributing to prolonged hospital admissions and poor outcomes.
Objective. To examine HAI incidence and risk factors in an intensive care unit (ICU) during high v. low occupancy periods.
Methods. This retrospective, descriptive analysis investigated HAI incidence among adult patients admitted to the ICU at Chris Hani Baragwanath (CHBH) during a high (H2019) and low (L2020) occupancy. Data were extracted from the clinical records of 440 eligible patients.
Results. We found an increased risk of HAI during H2019 compared with L2020 (relative risk (RR) 1.42, 95% confidence interval (CI) 1.03 - 1.94). The overall frequency density of HAI was 25/1 000 ICU days. There was no difference in the distribution of the site of infection (blood v. other) (p=0.27) or bacterial category (Gram stain) (p=0.62). Five organisms accounted for 89% of pathogens: Klebsiella (26%), Staphylococcus (21%), Acinetobacter (16%), Candida (16%) and Enterobacter (10%). The incidence of multidrug-resistant/extensively drug-resistant (MDR/XDR) organisms was 4.2-fold higher (95% CI 1.3 - 13.4) during H2019 compared with L2020. Logistic regression analysis revealed two independent predictors of nosocomial infection: ICU length of stay (odds ratio (OR) 1.12, 95% CI 1.02 - 1.22) and intercostal drain duration in days (OR 1.27, 95% CI 1.09 - 1.47).
Conclusion. High occupancy in the ICU was associated with an increased risk of HAI and a greater incidence of MDR and XDR pathogens. Increasing ICU length of stay and invasive device duration were independent predictors of HAI.
Keywords. Nosocomial, infection, hospital-acquired, ICU, bed occupancy, risk factor.

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Contribution of the study
Hospital-acquired infections are a common problem and cause of morbidity and mortality in intensive care units and general wards globally. However, there is very little literature on the topic from low- and middle-income countries. This study aims to provide insite into the unique factors that contribute to these infections in the South African context.

Hospital-acquired infections (HAIs) have been shown to increase all in-hospital mortalities from 22 - 40%,[1] with a mortality rate of 13% being attributed to these infections.[2] In a non-cardiac ICU setting, approximately 250 000 deaths can be attributed to nosocomial sepsis annually.[3] Studies from the USA estimate that 4.0 - 4.5% of patients admitted to acute care hospitals develop at least one HAI during their admission.[4,5] When considering ICU alone, an HAI incidence of 13.6/1 000 patient-days has been reported,[5] with the monetary cost of treating these infections reaching tens of billions of dollars.[6,7] The European prevalence of HAI is reported to be 7.1/100 patients.[8] This is several times higher in developing countries, at 15.5/100 patients and an ICU-acquired infection incidence of 47.9/1 000 patient-days.[9]

South African (SA) centres have produced few, contrasting data. Most notably, a 2020 study conducted in the trauma centre at Groote Schuur Hospital (Cape Town) found a low HAI incidence of only 3%.[10] This low incidence may be attributable to several factors including the trauma patient profile (young, male, few co-morbidities), implementation of care bundles (hand washing, use of gloves and aprons) and implementation of Enhanced Recovery After Surgery principles in the facility field.[10] Another 2020 study from the neurosurgical ICU at Nelson Mandela Academic Hospital (Mthatha) found a similar incidence of nosocomial infections (4.2%).[11]

Inadequate patient bed spacing, poor staff skills, difficult bed management systems and decreased adherence to basic infection prevention and control (IPC) guidelines all contribute to higher infection rates in busy wards. Multiple studies point to bed occupancies and high patient-to-nurse ratios as being among the most important, potentially modifiable, extrinsic risk factors.[12-19]

Ahoy *et al.*[17] found that patients in wards with bed occupancies above 80% had a 56% higher rate of contracting HAI compared with those in

wards with lower bed occupancies. Similarly, Borg *et al.*[18] described a significant increase in infections in both general wards and the ICU as patient load increased.

Important extrinsic risk factors for HAI include central venous catheter (CVC) placement, urinary catheter placement,[20] invasive mechanical ventilation[21] and blood transfusion.[22] Significant intrinsic risk factors identified include advanced age, comorbidities (diabetes mellitus, hypertension, chronic renal disease and chronic obstructive pulmonary disease), body mass index (high and low) and higher APACHE II score on admission.[22]

Similar risk factors have been found in the resource-limited setting, with comorbidities (specifically diabetes mellitus), extremes of age, malnutrition and immune suppression being particularly significant intrinsic factors.[23]

In this study, we examined the risk factors for HAI in the main ICU at Chris Hani Baragwanath Academic Hospital (CHBAH). This is a 24-bed mixed adult/paediatric unit, with an additional eight high-dependency beds. Medical, surgical, trauma, orthopaedic, obstetric and gynaecological patients are managed in this ICU. The primary objective of this study was to examine the role of bed occupancy in the acquisition of HAIs among adult patients. Our secondary objectives were to evaluate other independent intrinsic and extrinsic risk factors for the development of HAI and describe sites and implicated organisms involved in these infections.

Ethics

Approval for this study was granted by the Human Research Ethics Committee (Medical) (M220239) of the University of the Witwatersrand, and other relevant authorities prior to the collection of data.

Methods

Study design and setting

A retrospective, descriptive, cohort study was conducted in a closed, multidisciplinary ICU at a tertiary academic hospital in SA. The opportunity to investigate the impact of low bed occupancy was afforded during the 'lockdown' in March 2020, imposed upon SA due to the COVID-19 pandemic. The number of patients admitted to the ICU, which was not admitting COVID-positive patients, decreased significantly for several weeks during this period.

Study population

The study population consisted of patients (≥16 years) admitted to the ICU. Patients were enrolled into the study during a 'low bed occupancy' (L2020) period and a 'high bed occupancy' (H2019) period. In an attempt to enrol equal numbers in both groups, the L2020 period extended for 4 months from 1 April to 31 July 2020 (during the COVID lockdown period), while H2019 included only 2 months (April 2019 and July 2019). These periods were selected to obtain an adequate sample size to achieve the desired power and significance of the study while mitigating the effects of seasonality.

Data collection

Patient demographic, clinical and laboratory data were extracted from ICU clinical notes and databases into an electronic study database using Microsoft Excel.

HAI definition

Patients designated as having acquired an HAI in the ICU were defined according to the Centers for Disease Control and Prevention's (CDC) definition of hospital-acquired infection.[24]) This definition includes patients who did not have an infection or signs of an infection for the first 48 hours of admission, with subsequent identification of an infective organism on a specimen taken more than 48 hours after admission, or they clinically/biochemically developed convincing signs of infection, leading to treatment with empiric antibiotics after this period.

Sample size and statistical analysis

A target sample size of 570 patients was calculated to achieve a power of 80% with a significance of 5%, based on the assumption of a decrease in ICU HAI incidence from 50/1 000 patients to 10/1 000 patients. Statistical analyses were performed using Statistica® version 13.3 (TIBCO Software Inc., USA). Continuous variables were expressed as median (interquartile range (IQR)), and proportions/percentages were used for categorical variables. Continuous data were compared using the Mann-Whitney U test while proportions were compared using the χ^2 test. We used a logistic regression model to evaluate independent predictors of HAI. $P<0.05$ was considered statistically significant.

Results

We enrolled 440 patients into our study. Patient data were allocated to one of two groups: H2019 and L2020. Fig. 1 describes the study flow. Table 1 describes the characteristics of the study group. Bed occupancy (patient-days/available bed-days) for H2019 and L2019 was 57% and 38%, respectively.

Primary objective

The relative risk (RR) of contracting HAI in H2019 was 1.42 (95% confidence interval (CI) 1.03 - 1.94) times that in L2020. The overall frequency density was 25/1 000 ICU days, with a frequency density of 32/1 000 ICU days for H2019 compared with 19/1 000 ICU days for L2020. The incidence of HAI is shown in Table 2.

Secondary objectives

Predictors of HAI

Using a logistic regression model, we explored 11 potential predictors of nosocomial infection. These included patient age, simplified acute physiology score (SAPS) II, ICU length of stay, days with indwelling catheters (central venous lines, arterial lines and urinary catheters), number of catheters inserted (central venous catheters and arterial lines), days of mechanical ventilation, number of blood products transfused and indwelling intercostal drain days. In the final model, only ICU length of stay (odds ratio (OR) 1.12, 95% CI 1.02 - 1.22, p=0.014) and days of indwelling ICD (OR 1.27, 95% CI 1.09 - 1.47, p=0.019) significantly predicted HAI acquisition.

Type of infecting organism

A comparison of the infecting organisms isolated in H2019 and L2020 revealed no significant variation in the incidence of Gram-positive, Gram-negative or fungal organisms in isolation v. mixed infections (any combination of the above) (p=0.62). Fig. 2 shows the incidence of organisms as identified by microscopy. Gram-negative infections were the most frequently detected in both H2019 and L2020. Fig. 3 indicates the frequency of infection by culture-identified organisms. Notably, the patterns of infection in H2019 and L2020 were similar.

Multidrug-resistant and extensively drug-resistant organisms

The pattern of drug resistance revealed a higher distribution of the combination of multidrug-resistant (MDR) and extensively drug-

resistant (XDR) organisms in H2019, with a RR 4.2 (95% CI 1.3 - 13.4) compared with the L2020 period.

Site of infection

There were no significant differences in the site of infection (blood culture v. other sites) when comparing the H2019 and L2020 periods (p=0.27) (Fig. 4).

Discussion

The main finding of this study was that the relative risk of contracting HAI in the ICU was significantly increased during periods of high bed occupancy compared with periods of low bed occupancy. This correlates with the results of other studies and reviews examining bed occupancy as a risk factor for HAI.[12-14,17,18] Most of these studies included patients admitted to general wards as well as the ICU. Fridkin *et al.*[14] focused on CVC-associated infection in the ICU and found patient-days per month (a measure of occupancy) significantly increased HAI rates (p=0.01). This study, however, only considered CVC-related HAI in a surgical ICU, whereas our study looked at all HAI in a general adult ICU.

Interestingly, the incidence of HAI in our setting ranged from 19/1 000 - 30/1 000 patient-days. These values fall between data from ICUs in the USA (13.0/1 000 patient days)[5] and the developing world (47.9/1 000 patient days).[9] Unlike our study, the USA data includes ICUs that treated adults as well as neonatal and paediatric patients. Their reported HAI rates may also be subject to negative bias due to low reporting of surgical site infection (SSI) in that database.

Point prevalence studies from Greece, Spain, Norway and Slovenia found the prevalence of HAI to be between 25.4% and 41.7%, with ICUs having significantly higher rates of HAI[25-28] than other wards. It should be noted that variations in the definitions of HAI and methods of data collection used in these studies may impact the comparability of results.

When compared with other SA data, the overall rate of infection per admission was significantly higher in our study (10.45%) than in other studies: 3% in Groote Schuur Hospital

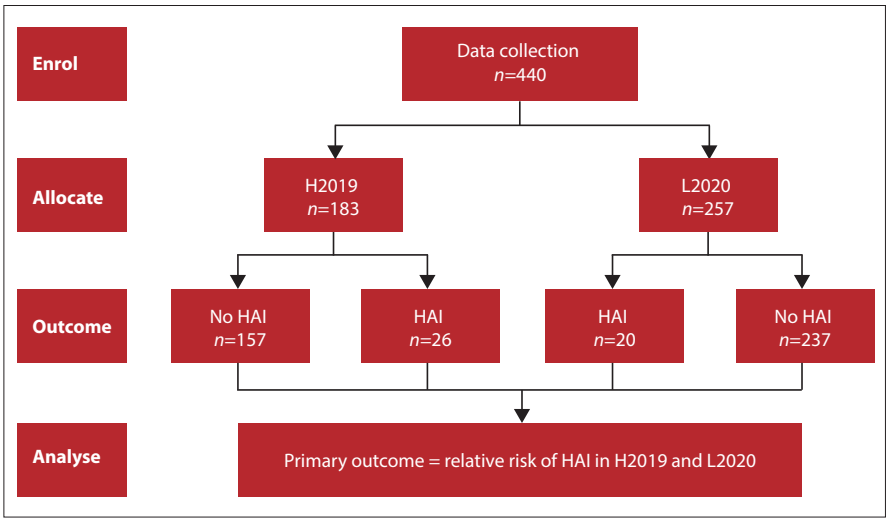

Fig. 1. Study design flow diagram. (H2019 = High occupancy in 2019; L2020 = low occupancy in 2020; HAI = healthcare-associated infection.)

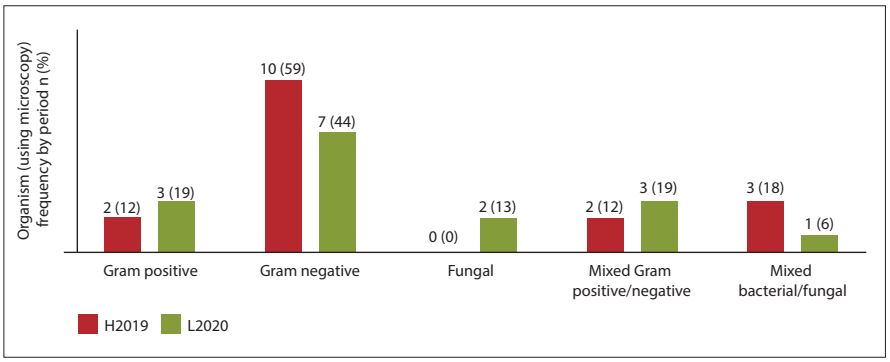

Fig. 2. Organism frequency count by microscopy for H2019 and L2020. (H2019 = High occupancy in 2019; L2020 = low occupancy in 2020.)

Table 1. Demographic details of patients by frequency for by period. (25 - 75 percentile)

Parameter	All *N*=440	Period 2019 *n*=183	Period 2020 *n*=257	*p*-value
Admission characteristics				
Age (years)	42 (30 - 57)	46 (32 - 62)	39 (28 - 55)	0.02
Male *n* (%)	238 (54)	94 (51)	144 (56)	0.33
SAPS II score (CI)	30 (22 - 44)	28 (22 - 40)	33 (22 - 47)	0.03
Pred. Mortality (CI)	25 (10 - 50)	10 (10 - 50)	25 (10 - 50)	0.02
Referring speciality				
Surgical	222 (50%)	90 (49%)	132 (51%)	0.65**
Medical	58 (13%)	24 (13%)	34 (13%)	
Orthopaedic	42 (9%)	24 (13%)	18 (7%)	
O&G	30 (7%)	7 (4%)	23 (9%)	
Trauma	88 (20%0	38 (21%)	50 (19%)	
Comorb.* (HIV)	52 (12%)	17 (9%)	35 (14%)	

SAPSI II = Simplified Acute Physiology Score II; Pred = Predicted; O&G = Obstetrics and Gynaecology.
*Comorbidity.
**p-value was calculated for surgical admissions v. all other disciplines between the two periods.

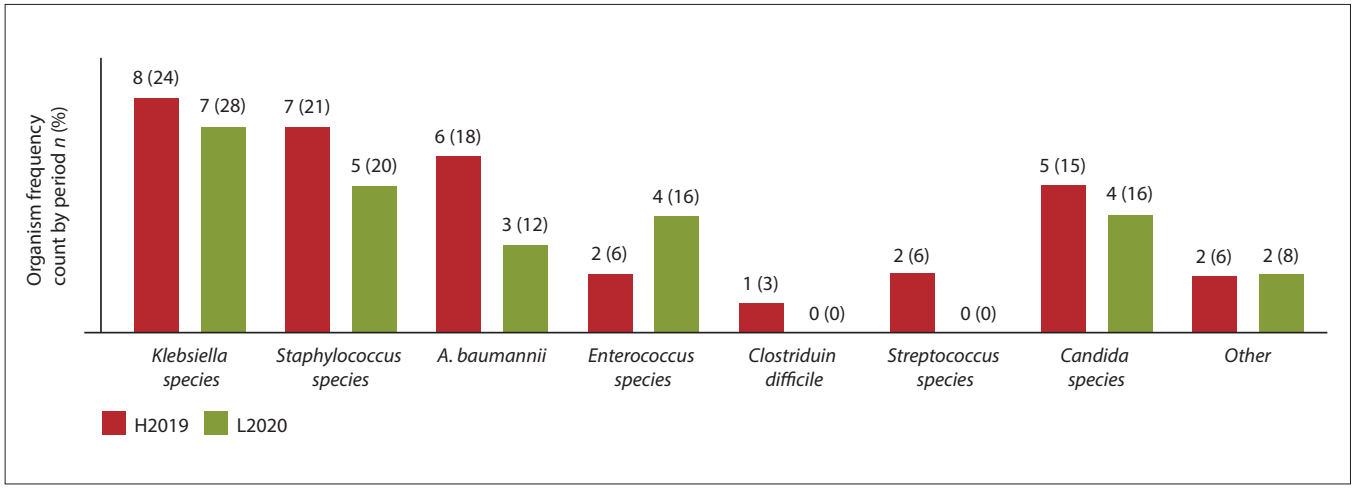

Fig. 3. Organism frequency count by culture for H2019 and L2020. (H2019 = High occupancy in 2019; L2020 = low occupancy in 2020.)

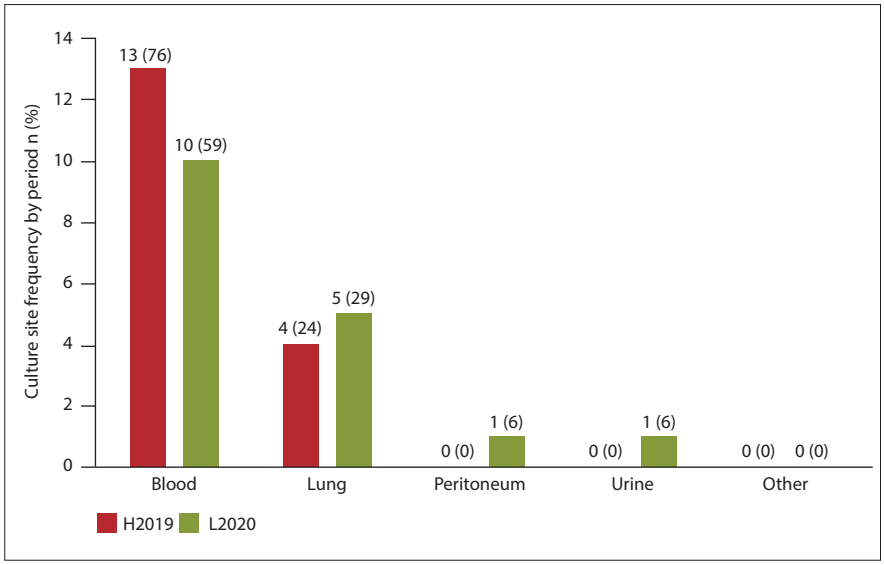

Fig. 4. Site of organism isolation frequency count for H2019 and L2020. (H2019 = High occupancy in 2019; L2020 = low occupancy in 2020.)

Table 2. Incidence of HAI

	Period (%)			
	All, (95% CI)	**H2019, (95% CI)**	**L2020, (95% CI)**	***p*-value**
HAI	10 (9 - 12) *n*=46	14.2 (12 - 17) *n*=26	7.8 (6 - 10) *n*=20	0.03
No HAI	90 *n*=394	85.8 *n*=157	92.2 *n*=237	
Total	*n*=440	*n*=183	*n*=257	

HAI = healthcare-associated infections; CI = confidence interval.
χ^2 = 4.71 for 2019 v. 2020 prevalence

(Cape Town)[10] and 7.5% in Nelson Mandela Academic Hospital (Mthatha).[11] There are prominent differences between these units and patient populations, compared with those in our study. The trauma centre in Cape Town admitted patients with a mean age of 32 years and consisted of high-care and ward patients rather than ICU patients. The mean age of patients admitted to the Nelson Mandela Academic Hospital neurosurgical ICU was 22.8 years, comprising adult, paediatric and neonatal patients, and included patients with multiple neurosurgical pathologies. Neither of these facilities treated medical patients. In contrast, the mean age of patients in our study was 42 years and only included adult ICU patients. Our study also included patients from a variety of other disciplines. Upon reviewing L2020 alone, the infection rate was 7.8%, in line with these SA studies. This contrasts the Eurobact study findings that ICU characteristics, including size, are not statistically important in determining HAI outcomes.[29] The setting of the Eurobact study is more comparable to ours than to other SA studies, with the mean age of patients being 59.5 years and a large proportion of medical admissions (58%).

There is a paucity of literature regarding HAI from other developing countries, especially those in Africa. An article by Allegranzi *et al.*[9] included data from developing countries, mostly in the Americas and Europe, with little from Asia and Northern Africa and none from countries in the Southern African Development Community (SADC) region.

The risk of infection with an MDR or XDR organism in our study was significantly higher in the high occupancy period. This is supported by data from within SA[11] and internationally.[21,29]

Klebsiella, *Staphylococcus aureus* and Acinetobacter were the three most frequently detected organisms in our study. This is similar to other data from the developing world where Klebsiella and *Staphylococcus aureus* are also responsible for a high number of HAIs.[9,11] Data from Europe provide a slightly different picture, with Acinebactor followed by Klebsiella being the most prominent infecting organisms, and *Staphylococcus aureus* being the fifth most prominent.[29] It is noteworthy that the European data had an older population, a greater burden of comorbidities and a higher number of medical admissions.

Our multivariate model highlighted the role of ICU days and the presence of invasive devices (ICD) for the development of HAI. There is a multitude of other studies that also found length of stay (LOS) and ICDs to be

related to HAI.[1,11,14,22,29] Two studies, in Malta[18] and Kentucky, USA,[21] found LOS not to be a significant risk factor, however, these were in a general ward setting and not ICUs. Other invasive devices, including CVC and invasive mechanical ventilation (IMV), have also been shown to predict HAI.[1,4,11,14,20-23] A large study from Stockholm, Sweden, over a 4-year period, also found age to be a risk factor for HAI.[1] Our study did not detect this relationship, possibly due to a small sample size.

Limitations

The quality of data was limited by the accuracy of that captured by medical staff while treating patients in the unit. There may also be missing data if files were incorrectly filed or missing from the records room at the time of data collection.

As only 440 eligible patients were admitted to the ICU during the study period, the sample size of our study did not meet the required number of 570 patients to achieve a power of 80% with a significance of 5%. Nonetheless, we feel that these findings are still noteworthy and add to the current pool of data regarding ICU-acquired infections.

Conclusion

High bed occupancy was associated with an increased risk of HAI and a greater incidence of MDR and XDR pathogens. Increasing ICU length of stay and invasive device duration (ICD) were independent predictors of HAI.

The findings of this study reinforce those from international studies and add to the limited pool of South African data describing ICU HAI rates.

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Author contributions. TW wrote the protocol, obtained ethical clearance and permissions to conduct the study, collected data and wrote the first draft of the article. DN assisted with writing the protocol and co-wrote the final article. SS assisted with writing the protocol, performed statistical analysis of the data and co-wrote the final article. All authors approved the final version of the article.

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Data availability statement. The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

Confl cts of interest. None.

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