Time-Series Analysis of the Impact of Bed Occupancy Rates on the Incidence of Methicillin-Resistant Staphylococcus aureus Infection in Overcrowded General Wards

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OBJECTIVE. We investigated the impact of bed occupancy, particularly overcrowding, on the incidence of methicillin-resistant Staphylococcus aureus (MRSA) infection in general ward settings.

METHODS. We performed a time-series and mixed-model analysis of variance of monthly incidence of MRSA infection and corresponding bed occupancy rates, over 65 months, in the medicine and surgical wards within St. Luke’s Hospital, a 900-bed tertiary care facility in Malta.

RESULTS. In the medicine wards, significant periodic fluctuations in bed demand were evident during the study period, with peaks of occupancy greater than 120% during the winter months. Cross-correlation analysis between the rate of bed occupancy and the rate of MRSA infection displayed an oscillatory configuration, with a periodicity of 12, similar to the periodicity evident in the autocorrelation bed-occupancy pattern. Further statistical analysis by means of analysis of variance confirmed that the months with excessive overcrowding tended to coincide with a significant increase in the rate of MRSA infection, occurring after a lag of approximately 2 months. Identical analysis of equivalent data from the surgical wards also revealed significant fluctuation in the rate of bed occupancy; however, occupancy never exceeded 100%. No cross-correlational relationship with MRSA infection incidence was present.

CONCLUSION. The study data suggest that, in our setting, simple fluctuations in the rate of bed occupancy did not have a direct impact on the incidence of MRSA infection as long as the rate of bed occupancy was within designated levels. Rather, it was episodes of significant overcrowding, with occupancy levels in excess of designated numbers, that triggered increases in infection incidence rates.

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Concern about the ever-increasing difficulties of ensuring adequate bed capacities within acute care hospitals has become commonplace in many countries. Pressure on hospital administrators to improve operational efficiency and an increase in emergency admissions combine to make our hospitals more crowded than ever because this increased demand is not being compensated by an increase in the number of beds provided.

The situation appears to be particularly acute in hospitals in developing nations, where overall whole-hospital bed occupancy rates of up to 120% have been reported. However, this state of affairs is by no means restricted to countries with limited resources. Hospitals in many Western countries are increasingly facing cost-containment challenges, which require a reduction in the number of inpatient beds and the need to work close to full occupancy.

In the United Kingdom, a report by the Audit Commission identified the average bed occupancy rate in National Health Service hospitals to be 95%. In such circumstances, episodes in which facilities are unable to cope with demand are more likely to occur. Stochastic simulation models suggest that hospital occupancy rates in excess of 85% substantially increase the risk of bed shortages and compromise patient safety.

Most of the concern about this state of affairs has long concentrated on the ability to ensure constant availability of empty beds to cope with fluctuations in the number of acute emergencies and to reduce waiting times for patients in the emergency department. Nevertheless, in recent years, additional concern about the possible impact of high rates of bed occupancy and overcrowding on the incidence of healthcare-associated infections, especially those caused by methicillin-resistant Staphylococcus aureus (MRSA), has emerged.

We have reported elsewhere a preliminary investigation at our institution into the possible link between bed occupancy and the incidence of MRSA infection in general ward settings.

The present work follows from that pilot study, with the substantial difference that rates of MRSA infection and bed occupancy rates were collected prospectively and were controlled for patient bed-days. More importantly, the resultant larger data set allowed us to undertake correlation analysis with more-informative time-series methodology.

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During the study period, St. Luke’s Hospital was the only tertiary care institution in Malta, a country with a population of approximately 400,000. The hospital was a 900-bed facility, with most general wards made up of mainly 4- and 8-bed bays and with most of the ward made up of larger Nightingale-type areas partitioned into 2-bed cubicles. Single rooms with en suite lavatory facilities were rare. Because of its unique status in the country and, therefore, the inability to limit the number of admissions at any one time, the hospital regularly experienced significant fluctuations in bed occupancy rates throughout the year, especially in the general medicine wards, where full occupancy was virtually continuous throughout the year. The problem became particularly acute during the winter months, when an influx of patients with respiratory illnesses invariably occurred. During peaks of activity and when full occupancy was exceeded, additional beds had to be obtained to cope with the pressures of the increase in hospital admissions. As a result, the general medicine wards experienced a considerable increase in the number of beds, well above their normal designated capacity. Attempts were made to increase the number of nursing staff on the wards in these situations through allocation of nurses from other wards on an overtime basis, although these efforts were not always successful. On the other hand, the demand for beds in the surgical wards was easier to control through management of the surgery schedule. Even though surgical wards were still subject to fluctuations in demand, they rarely, if ever, exceeded 100% occupancy.

**METHODS**

Data on new cases of MRSA infection were collected prospectively, from December 2000 through April 2006, through use of routine surveillance data collected from 8 general medicine wards and 8 surgical wards, each nominally with 30 beds. Patients with MRSA infection were included in the study only if the bacteriological investigation followed the presumptive diagnosis of an infection by the attending physician or surgeon in an individual with no history of MRSA infection and/or colonization in the previous year and in whom the culture sample had been obtained at least 72 hours after admission to the ward. No cases originating from surveillance cultures or follow-up investigations were used. The hospital did not operate an MRSA admission screening policy at any time during the study period. Incidence data were grouped into monthly mean rates for the respective specialties and then were converted into rates of infections per 10,000 bed-days, with use of available respective bed-stay statistics. The overall average bed occupancy was calculated as the monthly mean of the daily proportion of used beds from the standard designated number of beds of each of the wards under review.

A symmetric moving average was applied to the data to smooth out the random fluctuations and to make any present trend and seasonal behavior more evident. We used the sample autocorrelation (ACF) to measure the correlation between observations at various time intervals (lags). In this way, it was possible to infer certain characteristics of an observed time series; namely, randomness, short-term correlation, nonstationarity, and seasonal fluctuations, the latter evident as oscillations with the same frequency. To compare the 2 different time series, we then calculated the sample cross-correlation function (CCF) between readings of the bivariate process. ACF and CCF were deemed to be significantly different from 0 if they lay outside the interval $\pm 1.96/\sqrt{N}$. Statistical analysis was undertaken using SPSS software, versions 15 and 16 (SPSS).

Furthermore, to test whether months with more overcrowding differed in their effect on MRSA infection incidence from those months with lower occupancy, we also made use of mixed-model analysis of variance (ANOVA) with different correlational structures on the responses; namely, independent and identical distribution, first-order autoregression and first-order autoregressive moving average. This was done in view of the fact that the data under study pertained to stationary (possibly serially correlated) time series. We first transformed the bed occupancy time series into a binary time series by means of a cutoff point, taken to be the overall median bed occupancy in the medicine wards. Observations of the rate of MRSA infection were grouped into those with corresponding bed occupancy less than the median and those with corresponding bed occupancy greater than or equal to the median. In the case of bed occupancy of the medicine wards, the median cutoff point selected all periods of January through March in our sample, the months annually responsible for peaks in the hospital’s bed occupancy. Implementation of mixed-model ANOVA was then performed, with these 2 groupings determining the fixed effect. The fixed effect’s contribution to the incidence of MRSA infection on medicine as well as surgical wards was analyzed at lags 0, 1, 2, and 3, with the lags representing the number of months elapsed after the occurrence or, otherwise, of a certain bed occupancy grouping. The analysis of the surgical wards was undertaken as a comparison with the equivalent analysis for the medicine wards, because the former was not subject to overcrowding.

**RESULTS**

Over the 65-month study period, the median MRSA infection incidence in the medicine wards was found to be 6.68 infections per 10,000 bed-days (interquartile range, 4.83–8.03 infections), whereas the bed occupancy rate showed a median value of 110% (interquartile range, 103–115%; minimum, 91%; maximum, 124%). The ACF of the MRSA infection rate for the medicine wards was more indicative of a purely random series, with most of the autocorrelation coefficients lying within the confidence intervals around 0 (Figure 1A). The Ljung-Box test for randomness, yielding a $P$ value greater than .05 for various lags, further sustained this conclusion. On the other hand, the ACF for the hospital bed occupancy time-series data indicated a periodicity of 12, implying seasonal fluctuations in bed occupancy that pertained to the month of the year (Figure 1B). Bed occupancy tended to reach its peak in February and its lowest
level in July. This was, in fact, quite conspicuous from an order 3 simple-moving average plot (Figure 2) consisting of MRSA infection incidence as well as bed occupancy. The graph shows a clear pattern in bed occupancy, where the onset of the colder winter months from January until March resulted in an influx of patents, and the subsequent sharp increases in the bed occupancy levels reached peaks in excess of 115%. On the other hand, the moving average plot for MRSA infection incidence indicated that, in most of the years considered, a peak in the infection rate was reached only a few months after the peak in bed occupancy. In fact, peaks in bed occupancy occurred in February 2001, January 2002, February 2003, and February 2005, and maximum MRSA infection incidence invariably occurred 1-3 months later. This pattern was not discernable for 2004, when an outbreak in one of the wards in November may have distorted the normal patterns of endemicity. The time-series CCF between bed occupancy of the medicine ward and incidence of MRSA infection displayed an obvious oscillatory pattern, with a periodicity of 12 (Figure 1C). This was very similar to the periodicity evident in the sample ACF of the bed occupancy and reminiscent of the seasonal pattern depicted in the same figure. Although the CCF displayed no statistically significant coefficients for positive lags, it displayed significant coefficients at a negative lag of 1-2 months. Significant coefficients were also seen for some later negative lags, but their statistical significance was not seen to have any interpretable value, because it seemed to be largely the cause of a repetition of patterns in the bed occupancy rate and incidence of MRSA infection over the years being studied.

All 3 mixed-model ANOVA tests on the incidence of MRSA infection on the medicine wards confirmed that a statistically significant discrepancy existed only between the means of the 2 groupings for MRSA infection incidence at a lag of 2. This occurred with a mean rate of 7.26 infections per 10,000 bed-days for the more-overcrowded months and 5.79 infections per 10,000 bed-days in the other months (Table 1). However, for other lags, the same table showed no significant difference. In other words, MRSA infection incidence appeared to be significantly increased only 2 months after instances of severe overcrowding. In all cases, the marginal residuals arising from the mixed-model ANOVA satisfied the necessary random behavior.

During the same study period, the median bed occupancy rate in the surgical wards was 84% (interquartile range, 81%-90%). Bed demand still showed almost as much fluctuation as in the medicine wards, varying from a minimum of 68% to a peak of 97%, but the critical difference was that it never exceeded full occupancy. The median MRSA infection rate was 16.2 infections per 10,000 bed-days (interquartile range, 10.3-19.6 per 10,000 bed-days). The moving average plot for bed occupancy rate and MRSA infection incidence in the surgical wards gave an immediate indication that no relationship between the 2 series existed (Figure 3). This was further confirmed by largely insignificant cross-correlation coefficients, with none of the lags indicating statistical significance or periodicity. We also performed cross-correlation analysis between MRSA infection incidence and length of stay in both medicine and surgical wards, but again, no significant patterns or results could be discerned in either case. Moreover, mixed-model
analysis for data from the surgical wards (performed the same way as for their medicine counterparts and similarly taking the median as the cutoff point) showed no significant differences in MRSA infection rate between the months when bed occupancy rates were above and below the median (Table 1).

**Discussion**

Cunningham and colleagues\textsuperscript{12,13} studied the correlation between percentage bed occupancy rates and MRSA infection incidence for 11 acute hospital trusts in Northern Ireland for three 12-month periods, from 2001 to 2004, but were able to show a statistically significant relationship for only 1 of the study periods. Such an outcome is not surprising. As is clearly evident from our data, bed demand in most acute care hospitals tends to fluctuate over a whole year. Therefore, there is a risk that if data are averaged over 12 months, the results may miss any link that would be present only at certain periods of the year. Time-series analysis offers distinct advantages because it allows a series of observations to be studied over time, providing the possibility not only of analyzing the correlations of various variables simultaneously but also of identifying any past and future dependencies.\textsuperscript{14} Lopez-Lozano et al.\textsuperscript{15} used

![Figure 2](image_url)  
**Figure 2.** Simple moving average plots for methicillin-resistant *Staphylococcus aureus* (MRSA) incidence (black line) and corresponding rate of bed occupancy (gray line) in medical wards (2000-2006).

**Table 1.** Mean Rate of Infection due to Methicillin-Resistant *Staphylococcus aureus* (MRSA) at Various Monthly Lags

<table>
<thead>
<tr>
<th>Ward and lag</th>
<th>Mean no. of infections per 10,000 bed-days</th>
<th>Error (P value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
<td>Less than median bed occupancy</td>
</tr>
<tr>
<td>Medicine</td>
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<td></td>
</tr>
<tr>
<td>0</td>
<td>6.4118</td>
<td>6.7155</td>
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<td>2</td>
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<td>3</td>
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<tr>
<td>Surgical</td>
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<td></td>
</tr>
<tr>
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<tr>
<td>3</td>
<td>15.9471</td>
<td>17.7892</td>
</tr>
</tbody>
</table>

**Note.** Results are by grouping (below median bed occupancy or greater than or equal to median bed occupancy), with analysis of variance test on the impact of grouping on MRSA incidence for medicine and surgical wards. AR(1), first-order autoregression; ARMA (1,1), first-order autoregressive moving average; IID, independent and identical distribution.  

* Indicates statistical significance.
time-series methodology successfully to analyze the relationship over time between antimicrobial resistance and antibiotic use in a hospital setting.

It should be pointed out that CCFs should be interpreted with care when at least one of the series is unfiltered (ie, still contains trend or seasonality), because this carries some inherent risks of large and spurious cross-correlation coefficients. However, in our case, it did not make sense to correlate the MRSA infection-rate series with a deseasonalized bed occupancy series, when it was the periodic behavior of the bed occupancy series that was likely to have an impact on the MRSA infection-rate series and not any underlying irregular fluctuations of the bed occupancy from its average periodic behavior. Our CCF had the limitation that significance was found for only one specific negative value for the smaller lags, with a P value just below .05, whereas the positive lags did not show statistical significance. However, time-series texts emphasize the importance of identifying patterns in tools such as ACF and CCF, especially when indicative of trend or seasonal behavior. We conclude that it was this clear seasonal pattern in the medicine wards, evident in both the moving average plots and in the CCF, that suggests the existence of a relationship between bed occupancy rate and MRSA infection incidence. The confirmation by the mixed-model ANOVA model adds further weight to this conclusion. The lack of statistical significance in the positive lags of the CCF could simply be attributable to the fact that it was not merely an increase in the bed occupancy rate that triggered a rise in MRSA infection incidence but the actual instances of severe overcrowding. Furthermore, a peak in the incidence of MRSA infection was not achieved immediately; a lag of approximately 2 months was necessary for this to happen. This phenomenon could be explained by the role of colonization in the dynamics of MRSA infection. Cooper and colleagues have illustrated the impact that asymptomatic colonized patients in a hospital had on the subsequent infection rate in the hospital. It would be reasonable to postulate that the identified 2-month lag may be the time required for colonization to increase to a level at which clinically relevant infections start to become evident among the colonized cohort in the wards.

There are various possible ways in which overcrowding and excessive bed occupancy can have an impact on the incidence of multiresistant infections such as those due to MRSA. In many instances, a sharp increase in patient complement will not be mirrored with an equivalent addition of nursing and other ancillary ward personnel. This was often the case in our institution, where, despite administrative attempts to increase nursing personnel in the wards, the limited availability of nursing staff in Malta made it difficult to recruit additional staff. In any infection that is transmitted predominantly by contact, reduced staffing levels and greater-than-average workloads are likely to have a major negative effect by reducing the time available for the performance of infection control interventions, especially hand hygiene. In fact, it has been shown that nurses’ compliance with hand hygiene is lowest at the periods of time when nurses are most busy, whereas several studies have identified increased rates of healthcare-associated infection at times of significant increases in nursing workload. The issue is, however, even more complex than simple staffing levels. The demands on nurses that take place during periods with high rates of bed occupancy are usually unable to be met by the regular staff complement. Allocation of additional nurses on an overtime basis, from other wards, or through an agency is often required. However a lowered ratio of regular-to-
temporary nurses has been identified as conducive to the transmission of nosocomial infection, as has a lowered proportion of nurses to nursing aides. In addition, there is evidence that other factors may also play a role in the transmission of infection. Kibbler and colleagues noted a 3-fold increase in MRSA colonization when an additional bed was placed in a 4-bed ward bay. This increase in colonization occurred despite the provision of additional trained nursing personnel, whose percentage increase was actually greater than the proportional escalation in patient numbers. This led Kibbler and colleagues to suggest that airborne transmission may have played a role. A more recent publication by Wilson and coworkers showed a correlation between the number of patients with MRSA infection and the number of MRSA-positive air samples. Shiomori and colleagues identified significant increases in airborne MRSA counts during the times that beds were made in rooms housing patients with MRSA infection. Such particles will ultimately settle in the vicinity of the patient and contaminate the ward environment, where the pathogens may conceivably contaminate the hands of health care workers and result in subsequent transmission of infection to patients. An overcrowded ward, especially one in which extra beds have been added, is a more likely scenario for such a transmission scenario. Not only are fomite-generating procedures more intense because of the increase in patient numbers, but because the space between beds is reduced, the potential for airborne organisms to play an important role in transmission is even more relevant. There is yet another factor to be addressed as a potential cause of the increase in MRSA infection incidence at periods of high bed occupancy, particularly in our case, where the peaks typically occurred during the winter months. Monnet and colleagues describe temporal relationships between the percentage levels of methicillin-resistance in Staphylococcus aureus isolates and the use of various antibiotics, including macrolides, third-generation cephalosporins, and quinolones. Similar correlation between antibiotic use and resistance has been described by the ARPAC (Antibiotic Resistance; Prevention and Control) project, citing again both macrolides and cephalosporins, as well as total antibiotic use (except glycopeptides). A major constituent of the influx of medical patients in our hospital during the winter months were elderly patients with respiratory infections. Most of these patients were treated with at least 1 antibiotic; macrolides and respiratory quinolones were among the most commonly prescribed. Bignardi and Askew reported similar observations during peaks of influenza activity. They noted a higher incidence of both infection due to MRSA as well as Clostridium difficile during these times of the year and postulated that increased antibiotic use may have been a factor, in addition to reduced hygiene standards, understaffing, and inadequate isolation facilities.

In conclusion, we hypothesize that, in our setting, it was not simply an increase in bed occupancy rate that seemed to trigger an increase in the incidence of infection due to MRSA, but it was the episodes of severe overcrowding, with occupancy rates well in excess of optimal levels. This, we believe, is the major inference from our work and adds to the conclusions reached in our pilot study. Our results continue to emphasize the impact of hospital overcrowding on the transmission of healthcare-associated infections. They support the need for individual hospitals to establish their optimal and maximum bed occupancy levels and for managers and administrators to have adequate planning and resources in place to avoid exceeding them. It also puts into perspective the feasibility of political targets for MRSA infection rate reduction or the institution of search-and-destroy policies if they are not accompanied by appropriate funding and support to correct underlying bed-availability problems.

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