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ORIGINAL ARTICLE

A cross-sectional study of neonatal intensive care unit overcrowding and understaffing associated with bacterial outbreaks

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Abstract

Aim: To study whether overcrowding and/or nurse understaffing preceded four bacterial outbreaks during a 5-year period in a Norwegian university hospital neonatal intensive care unit (NICU).

Methods: A repeated cross-sectional study based on prospectively collected data from the Norwegian neonatal network's (NNN) web-based electronic database, digital work schedules and information about the outbreaks from logs, reports and publications. Number of admitted patients, category 4–5 patients (i.e., with the highest nurse to patient ratio), rostered nursing staff and nurse specialists were analysed in relation to periods (1) >28 days before individual outbreaks, (2) ≤28 days before, (3) during and (4) after outbreaks. Overcrowding and understaffing were compared between the four periods with Chi-square test and post hoc analysis with Bonferroni correction.

Results: When all outbreaks were analysed together, overcrowding was more frequent in the periods within 28 days of outbreaks compared to the other periods ($p < 0.001$). For understaffing, the periods within 28 days of outbreaks were only different from the periods >28 days before outbreaks ($p < 0.001$). The trends regarding individual outbreaks were less consistent, but there were more category 4–5 patients before and during the outbreaks.

Conclusion: Bacterial outbreaks in a 5-year period were weakly associated with overcrowding and understaffing.

KEYWORDS
colonisation, neonatal intensive care unit, outbreak, patient occupancy, staffing

1 | INTRODUCTION

A Norwegian university hospital neonatal intensive care unit (NICU) experienced four bacterial outbreaks, in 2008–2009, 2016, 2019 and 2020–2021, respectively. Three of these outbreaks were with multi-resistant bacteria.

Bacterial outbreaks are particularly concerning when they occur in a NICU setting. Premature and sick newborn infants have

Abbreviations: CI, Confidence Interval; ESBL, Extended Spectrum Beta-Lactamase; IQR, Interquartile range; MRSA, Methicillin-resistant *Staphylococcus aureus*; MRSL, Methicillin-resistant *Staphylococcus lugdunensis*; NICU, Neonatal intensive care unit; NNN, Norwegian neonatal network; NPR, Nurse to patient ratio.

immature immune systems, invasive vascular and airway accesses, and many infants are cared for in open-bay units.[1] Multiple-use medical equipment is frequently used, and the open-bay areas are not suited for optimal infection control.[2] Bacterial outbreaks may put strains on the nursing staff, as evident from a dramatic increase in sick leaves and resignations directly related to the number of colonised patients per week during a NICU outbreak.[3] Thus, bacterial outbreaks in the NICU have large negative health economic consequences. The estimated costs of a single outbreak in a Norwegian NICU were USD 430,000.[4] Outweighing the economic costs is the increased morbidity and mortality resulting from outbreaks.[2]

By identifying contributing factors, targeted efforts to reduce the risk of future outbreaks can be made.[5] A review article reporting on adult intensive care units included five studies that described associations between understaffing, increased workload and outbreaks.[6] A methicillin-resistant *Staphylococcus aureus* (MRSA) outbreak in a Norwegian NICU was believed to be related to overcrowding, understaffing, frequent relocation of patients and circulation of nurses.[4] Three NICU studies found that the incidence of the outbreak-causing bacteria was significantly higher during periods of severe overcrowding and understaffing.[7–9] A recent German study found that there was a significant negative correlation between nursing coverage and the number of colonised and infected infants.[3]

Several of the previous studies focus only on the actual outbreak period. The four outbreak periods in our unit were of relatively short durations. Based on this as well as staff perceptions, the hypothesis of the current study was that outbreaks in our NICU were *preceded* by periods of patient overcrowding and/or nurse understaffing, and the primary aim of this study was to test this hypothesis. Therefore, in a cross-sectional study with data from the Norwegian neonatal network's web-based electronic database, digital work schedules and reports, we analysed rates of overcrowding and understaffing to estimate their association with the bacterial outbreaks.

Key Notes

- Overcrowding and nurse understaffing were speculated to precede four bacterial outbreaks in a university hospital neonatal intensive care unit.
- When all outbreaks were analysed together, the 28 days immediately preceding the outbreaks had a higher fraction of days with overcrowding and nurse understaffing than the periods >28 days before outbreaks.
- By identifying contributing factors, targeted efforts to reduce the risk of neonatal intensive care unit bacterial outbreaks can be made.

2 | METHODS

2.1 | Setting and study design

This project was designed as a repeated cross-sectional study in a Norwegian university hospital level 3c NICU (cares for sick term infants and premature infants from gestational week 23 + 0).[10] The NICU has a catchment area covering around 4500 annual deliveries and is a regional referral unit. Nine to ten percent of all inborn neonates are admitted to the NICU, corresponding to an estimated annual 450 admissions and 5000 hospital days. The current physical unit was established in 1992 with 21 beds. In 2019, this number was reduced to 16. After the outbreak in 2016, the infection prevention and control (IPC) department recommended only 12 patients in the three open bays (intensive care [$n = 4$], intermediate care [$n = 4$] and nursery [$n = 4$, including one isolation room]). The remaining beds are in single-family rooms with telemetry surveillance.

2.2 | Characteristics of the outbreaks

1. 2008–2009: Extended spectrum betalactamase (ESBL)-producing *Klebsiella pneumoniae*.[11] Fifty-eight infants were colonised 27 November 2008–17 April 2009, i.e., 142 days. One patient developed clinical sepsis and no infant died from the outbreak bacteria. The strain was cultured in 3/18 breast milk samples. Thirty-three out of 512 environmental samples were positive. Thirty out of 80 staff were screened and were all negative.
2. 2016: *K. pneumoniae* with normal resistance pattern. Thirteen patients were colonised 8 March–15 June, i.e., 100 days. Three patients developed clinical sepsis, two of them died.
3. 2019: Klebsiella ESBL. Three patients were colonised 19 November–4 December, i.e., 16 days. One of the colonised patients died during the outbreak, but from a cause found to be unrelated to the colonisation. The last colonised patient was discharged 24 February 2020, but since this was the only colonised patient after 4 December, the unit returned to normal routines that day with the colonised patient remaining with contact-isolation until discharge.
4. 2020–2021: *Staphylococcus lugdunensis* resistant to methicillin (MRSL). Four patients were colonised 14 December 2020–19 February 2021, i.e., 68 days. Two patients developed clinical sepsis, but only one had a positive blood culture. Two of the breast milk samples were positive, whereas the environmental samples were all negative. Three staff tested positive and had the MRSL successfully eradicated following the same decolonisation procedure as for MRSA.

2.3 | Screening and cohorting procedures

The NICU does not employ routine bacterial screening. All outbreaks were random findings resulting from cultures of, e.g., eye secretions and blood from symptomatic infants. The outbreaks in 2016, 2019 and 2020–2021 were detected in the intensive care bay. In 2016, the outbreak spread to the entire unit, while the outbreaks in 2019 and

2020–2021 remained only in the intensive care bay. The outbreak in 2008–2009 was first detected when 25 out of 26 patients were colonised, and thus affected the entire unit.

During outbreaks, recently discharged patients were tested, and admitted infants were screened several times a week. Environmental samples were taken from sinks and other surfaces, breast milk and breast pumps. Staff were only screened in two of the four outbreaks. Genetic testing of the outbreak bacterium was performed to exclude other strains. During the outbreak in 2016, although 18 other strains of *K. pneumoniae* were discovered, the 13 outbreak patients were colonised with the same strain. Screening protocols and their duration were based on findings specific to the individual outbreak and agreed upon in close dialogue with the IPC department.

During the 2008–2009 and 2016 outbreaks, IPC measures included that the patients were cared for at two separate locations and physically separated into cohorts of colonised, exposed and newly admitted patients. New patients were screened on admission, and regular sampling of all patients was performed.

2.4 | Study period, participants and data extraction

The study is based on prospectively collected data from the Norwegian neonatal network's (NNN) web-based electronic database, digital work schedules and information about the outbreaks from daily written logs during the outbreaks, internal reports made after outbreaks and publications. Data were extracted from the 5 years and 2 months the unit had bacterial outbreaks: 2008–2009, 2016, 2019 and 2020–2021. We intended to include the whole year the unit had an outbreak, and 2 years when the outbreak included two calendar years. However, since the project and data extraction started March–April 2021, only 2 months (January and February) of 2021 were included. The unit of analysis was each day during the outbreaks, as well as >28 days before each outbreak, ≤28 days immediately before, and after the outbreaks. The outbreak in 2008–2009 was first detected 20 January 2009. However, as the index case was traced back to 27 November 2008, 8 weeks before the outbreak was detected, the period "immediately before" the outbreak was also extended to 84 days (12 weeks).

Patient activity data each day of the total 5 years and 2 months were extracted from NNN (n = 1887). The patient occupancy was calculated by collecting the number of patients in each category (1–5: 1 = lowest complexity, 5 = highest complexity/acuity[10]) admitted to the unit each day during the outbreak years. The number of patients in category 4 and 5 each day was analysed separately to study if the outbreaks were related to more patients needing a higher nurse to patient ratio (NPR).

The desired number of nurses each day was estimated based on the Norwegian Directorate of Health's recommended NPR.[10] For a shift, the desired number of nurses was calculated from the following: number of category 1 patients × 0.33 + number of category 2 patients × 0.4 + number of category 3 patients × 0.75 + number of category 4 patients × 1 + number of category 5 patients × 1.5.[10]

Information about the actual staffing was collected from the hospital's electronic software for work time planning (GAT, Visma), and the desired number of nurses was compared with the actual unit staffing each day during the evening shift, i.e., the shift with the lowest NPR, except the night shift. Due to a lower unit activity at night (lower risk of bacterial transfer), evening shifts were chosen over night shifts.

For the outbreaks in 2019 and 2020–2021, the number of nurse specialists as an indirect measure of nursing staff competence was also retrieved for each shift.

2.5 | Ethical considerations

The project was approved by the hospital privacy legislation authority (reference number 2461) as a quality assurance project and was thus exempt from review by the Norwegian centre for research data and the Regional Committee for Health Research Ethics.

2.6 | Definitions

An outbreak is defined by the Norwegian institute of public health as two or more cases of the same disease and with suspected/assumed common source.[5] In this study, an outbreak-period was defined from the first colonised patient (index case) until the discharge of the last patient, except for in 2019 when the end of the outbreak period was defined when the unit returned to normal, although one colonised patient was still admitted with contact-isolation.

Colonisation is defined as a positive culture with the bacteria in question, but no need for antibiotic treatment. Infection is defined as a need for antibiotic treatment for the bacteria in question.[13]

A nurse specialist is defined as a nurse with postgraduate training in intensive care-, neonatal- or paediatric nursing. The Norwegian Directorate of Health recommends that NICUs have nurse specialists on all shifts.[10]

The definition of overcrowding is based on the number of unit beds, i.e., 21 prior to 2019 and 16 after 2019. Thus, overcrowding was defined as >21 patients for the 2008–2009 and 2016 outbreaks and >16 for the 2019 and 2020–2021 outbreaks.

Understaffing is defined based on national NICU staffing norms as previously described. By calculating the desired NPR based on the patient occupancy each day, and further comparing it with the actual staffing in the workplan, the unit is defined as overstaffed, appropriately staffed or understaffed. If the NPR in the work schedule was lower than the calculated need, this was defined as understaffing.

2.7 | Statistical analyses

To examine the prevalence of overcrowding and understaffing, descriptive statistics were used. Outbreak-years were divided into four

periods: (1) >28 days before the outbreak, (2) within 28 days of the outbreak (adding an extended period for the 2008–2009 outbreak), (3) the outbreak-period and (4) after the outbreak, and crosstabulations were made to compare these periods with regard to overcrowding and understaffing as dichotomous variables (yes/no). Post hoc tests with Bonferroni corrections were performed. Pearson Chi-square test was used to compare periods in immediate relation to the outbreaks (periods 2 and 3) to periods not in immediate relation to the outbreaks (periods 1 and 4).

Non-parametric tests for continuous variables (Kruskal-Wallis) were used to test for differences in the number of level 4–5 patients and nurse specialists. To examine the direction of potential differences in the number of level 4–5 patients, box-and-whisker plots were made.

Categorical variables are presented as number with percent and continuous variables as mean with confidence interval (CI) or median with interquartile range (IQR). *p*-Values are 2-sided and significance level Bonferroni corrected to <0.0062. Time plots were made in Excel 16.55 (Microsoft) to visualise overcrowding and understaffing in relation to the outbreaks. Statistical analyses were performed with IBM SPSS 27 for Mac and IBM SPSS 26 for Microsoft Windows (IBM Corporation).

3 | RESULTS

A total of 1887 days distributed between period 1 (956 days), period 2 (112 days), period 3 (326 days) and period 4 (493 days) were analysed. When using an extended period 2 for the 2008–2009 outbreak, the days were distributed as follows: period 1 = 956 days, period 2 = 168 days, period 3 = 270 days and period 4 = 493 days.

3.1 | Overcrowding

A total of 424/1887 (22.5%) days were overcrowded, with (1) 22.1% of the days in the periods >28 days before outbreaks, (2) 39.3% of the days in the periods within 28 days of the outbreaks, (3) 22.1% of the days during outbreaks and (4) 19.7% of the days in the periods after the outbreaks (Table 1). The period within 28 days of the outbreaks was significantly different from the other three periods ($p < 0.001$). When using an extended period 2 for the 2008–2009 outbreak, we found overcrowding in: (1) 22.1% of the days in the periods >28/84 days before outbreaks, (2) 33.9% of the days in the periods within 28/84 days of the outbreaks, (3) 21.9% of the days during outbreaks and (4) 19.7% of the days in the periods after the outbreaks. The period within 28/84 days of the outbreaks was significantly different from the other three periods ($p < 0.001$).

The periods not in immediate relation to the outbreaks (periods 1 and 4) had 308/1.449 days (21.3%) with overcrowding compared to 116/438 days (26.5%) with overcrowding in the periods in immediate relation to the outbreaks (periods 2 and 3) ($p < 0.001$).

Analysing each outbreak-period separately, overcrowding preceded (within 28 days of) all four individual outbreaks, but significantly only in 2008–2009, 2016 and 2020–2021, most prominently in the 2008–2009 outbreak (Figure 1).

3.2 | Understaffing

A total of 1091/1887 (57.8%) days were understaffed, with (1) 47.5% of the days in the periods >28 days before outbreaks, (2) 75.0% of the days in the periods within 28 days of the outbreaks, (3) 61.3% of the days during outbreaks and (4) 71.6% of the days in the periods after the outbreaks (Table 1). The periods within 28 days of outbreaks had a significantly higher fraction of days with understaffing than the periods >28 days before outbreaks ($p < 0.001$), but did not differ significantly from the other two periods. When using an extended period 2 for the 2008–2009 outbreak, we found understaffing in: (1) 47.5% of the days in the periods >28/84 days before outbreaks, (2) 81.6% of the days in the periods within 28/84 days of the outbreaks, (3) 54.4% of the days during outbreaks and (4) 71.6% of the days in the periods after the outbreaks. The periods within 28/84 days of outbreaks had a significantly higher fraction of days with understaffing than the periods >28/84 days before outbreaks and during the outbreaks ($p < 0.001$), but did not differ significantly from the periods after outbreaks.

The periods not in immediate relation to the outbreaks (periods 1 and 4) had 807/1.449 days (55.7%) with understaffing compared to 284/438 days (64.8%) with understaffing in the periods in immediate relation to the outbreaks (periods 2 and 3) ($p < 0.001$).

Analysing each outbreak separately, nurse understaffing preceded (within 28 days of) two individual outbreaks (2008–2009 and 2019), most prominently in the 2008–2009 outbreak. In the 2016 outbreak, understaffing was higher both >28 days before and within 28 days of the outbreak. In the 2020–2021 outbreak, no consistent pattern could be identified. Figure 1 are graphical presentations of understaffing and overcrowding before, during and after outbreaks.

3.3 | Category 4–5 patients and number of nurse specialist

There were more category 4–5 patients before and during outbreaks (Figure 2). The same pattern was not seen for category 1–3 patients.

In the 2019 and 2020–2021 outbreaks, there was a difference between periods 1 and 4 in the number of nurse specialists ($p = 0.002$) with a higher number of nurse specialists during the outbreaks (Table 1).

4 | DISCUSSION

In this cross-sectional study of four NICU bacterial outbreaks, when all outbreaks were analysed together, there was a difference in both

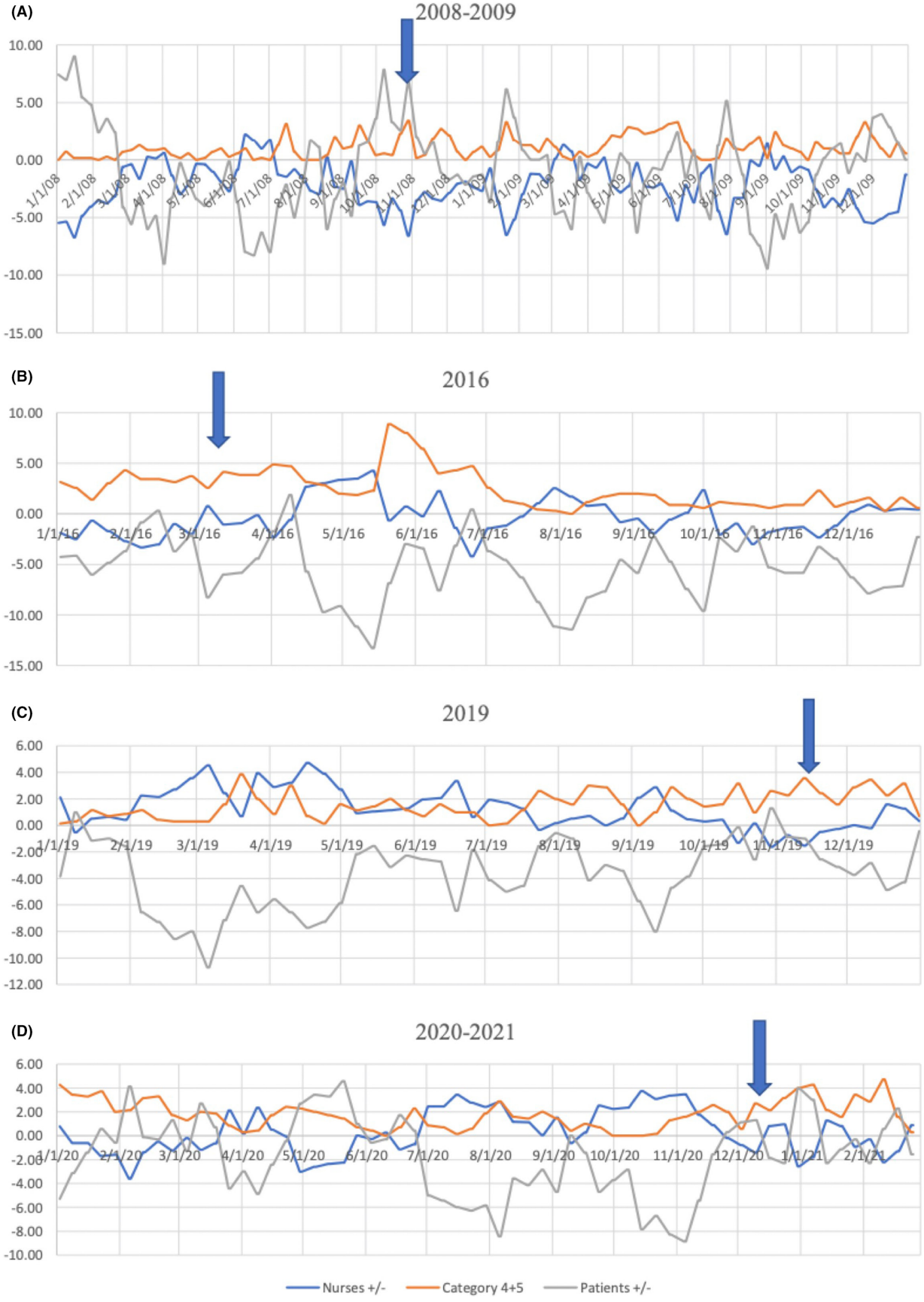

FIGURE 1 Graphical presentations of understaffing, overcrowding and category 4 + 5 patients before, during and after outbreaks. The unit on the *y*-axis is number of nurses, category 4 + 5 patients and total number of patients, the unit on the *x*-axis is date (month/day/year). The blue arrows mark the start of each outbreak. (a) Outbreak 2008–2009. (b) Outbreak 2016. (c) Outbreak 2019. (d) Outbreak 2020–21

TABLE 1 Understaffing, overcrowding and nurse specialists* the four periods related to outbreaks

	>28 days before outbreak ($n = 956$)	≤28 days before outbreak ($n = 112$)	Outbreak- period ($n = 326$)	After outbreak ($n = 493$)
Number (%) understaffing	454 (47.5)	84 (75.0)	200 (61.3)	353 (71.6)
p-Value	<0.001[a]	<0.001[b,c]	0.16[c]	<0.001[b]
Number (%) overcrowding	211 (22.1)	44 (39.3)	72 (22.1)	97 (19.7)
p-Value	0.67[a]	<0.001[b]	0.86[a]	0.08[a]
Mean (CI) nurse specialists	3.80 (3.69–3.90)	3.71 (3.38–4.04)	4.27 (3.99–4.56)	3.31 (2.86–3.75)

Note: Each superscript letter denotes a subset of period related to outbreak categories whose column proportions do *not* differ significantly from each other at the 0.05 level. Bonferroni corrected *p*-value <0.0062. 95% Confidence Interval (CI).

*The number of nurse specialist was only analysed for the 2019 and 2020–21 outbreaks.

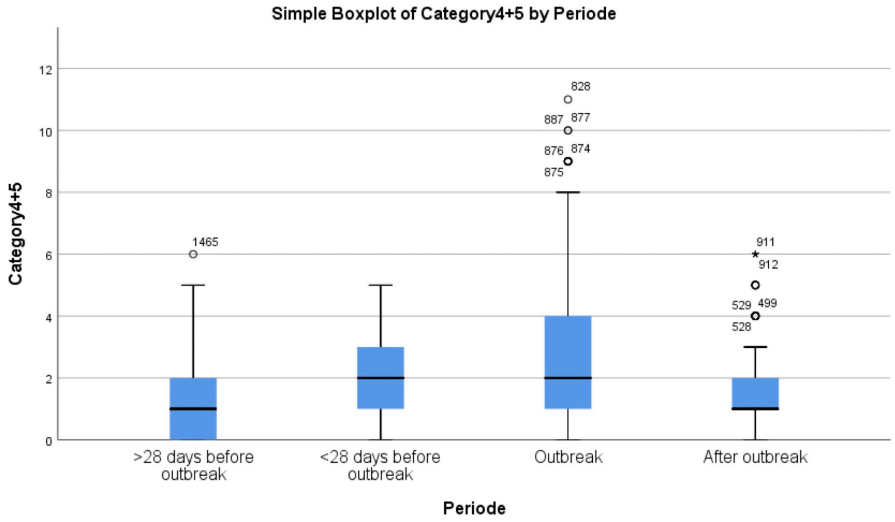

FIGURE 2 Boxplot of Category 4 + 5 patients. The unit on the *y*-axis is number of category 4 + 5 patients, the *x*-axis is period. The thick black line is the 50 percentile, and the box is bounded by the 25th and 75th percentiles.

overcrowding ($p < 0.001$) and understaffing ($p < 0.001$) between four periods with a different temporal relationship to the outbreaks. For overcrowding, the periods within 28 days of the outbreaks were significantly different from the other three periods ($p < 0.001$), with almost twice as many days with overcrowding. When using an extended period 2 for the 2008–2009 outbreak, the periods within 28/84 days of the outbreaks were still significantly different from the other three periods ($p < 0.001$). When it comes to understaffing, the periods within 28 days of the outbreaks were significantly different from the periods >28 days before outbreaks, but did not differ significantly from the other two periods. When using an extended period 2 for the 2008–2009 outbreak, the periods immediately preceding outbreaks were significantly different from both the periods >28/84 days before outbreaks and the outbreak periods. As many as 81.5% of the 28/84 days before outbreaks were understaffed. The periods not in immediate relation to the outbreaks had less overcrowding and understaffing compared to periods in immediate relation to the outbreaks.

The trends regarding individual outbreaks were less consistent, with three outbreaks being preceded by overcrowding and nurse understaffing, and one not being preceded by neither overcrowding nor understaffing. Overcrowding and understaffing were most evident prior to the 2008–2009 outbreak.

Several other studies have shown associations between bacterial outbreaks, overcrowding and understaffing.[3,7–9] Even though understaffing was the most frequent risk factor for outbreaks, a systematic review showed that understaffing was infrequently addressed by interventions.[13] In our study, almost 60% of the days were understaffed. The Norwegian Directorate of Health recommends considering increasing staffing levels if the unit has a higher staffing need than planned for a prolonged period of time.[10] Adding one nurse to each of the shifts in this study, the fraction of days with understaffing would be reduced to 42%.

Norwegian norms only take into account nurses working with direct care of patients, and not the need for a shift leader to coordinate the shift.[10,12] Adding a shift leader to the number of desired nurses per day/shift, the fraction of days with understaffing would increase to 73%. In addition, the need for one or more nurse(s) to admit new patients has not been accounted for by the norms.[12] Norwegian NICUs do not have a dedicated resuscitation team, and bedside nurses may have to go to the labour and delivery rooms to stabilise and admit new patients to the NICU. One study showed a reduction in the outbreak bacteria when a dedicated resuscitation nurse on each shift was implemented as one of several measures.[8]

Three out of four outbreaks were preceded by a period of overcrowding and understaffing. However, in the study period, several

periods with overcrowding and understaffing were not followed by an outbreak. This indicates that other factors than overcrowding and understaffing contribute to bacterial outbreaks in our NICU. More complex patients with intensive care needs were admitted before and during the outbreaks, a pattern not consistently seen for the less complex category 1–3 patients. Category 4 and 5 patients may be those on invasive mechanical ventilation and/or with multiple-organ failure, and should have an NPR of 1–1.5.[10] In intensive care, clinical changes and a need for life-saving and stabilising measures are sudden and unpredictable.[10] Category 4 and 5 patients are per definition in an unstable condition and need two pairs of nursing hands during care, interventions and treatment. Acute and planned requirements for extra hands result in nurses having to move between several patients during a single shift, and in acute events, there is limited time to perform optimal hand hygiene. Patient isolation increases the resource intensiveness of care. Thus, patients in isolation (due to colonisation) are assigned to a higher patient category. This may have contributed to a higher number of category 4 patients during, but not immediately prior to the outbreaks.

In 2019 and 2020–2021, the number of nurse specialists was quite stable. Still, there was a higher number of nurse specialists during the outbreaks compared with the other periods. Contrary to this, a study from Mexico showed a significantly lower proportion of trained nurses caring for critically ill patients during epidemic periods of ESBL-producing *K. pneumoniae*.[14] In our unit, as mentioned, there were more category 4–5 patients before and during outbreaks. According to The Norwegian Directorate of Health, category 4–5 patients should be cared for by nurse specialists on each shift,[10] which may explain the higher number of specialists during these periods.

Other potential risk factors for outbreaks in our unit include the distribution of patients in the three open bays where only a total of 12 patients is recommended. This recommended number is often exceeded. A limitation of this study is that the distribution of patients in the different bays and rooms is unknown. The unit had several category 4–5 patients before outbreaks. Thus, it is likely that more than four patients were cared for in the intensive care bay where most of the outbreaks were detected. Relocation of patients and circulation of nurses could also play a role. Before an MRSA outbreak in a Norwegian NICU, several patients had been moved and there was an extensive cross-over of health personnel.[4] In our unit, patients are relocated relatively often to compensate for low staffing levels and limited space.

Cross-sectional studies are subject to what is known as "ecological fallacy" and have limitations related to causal inference.[15] However, there is less concern when the associations produced carry a high biological plausibility and have previously been demonstrated, such as in our study. The first outbreak in 2008–09 has a huge impact on the results of this study, and in this specific outbreak there were 8 weeks between the index case and the detection of the outbreak. Thus, the actual start of and the period "in immediate relation to" the outbreak are difficult to define. To get around this problem, we extended the period preceding this outbreak from 4 weeks to 12 weeks in additional analyses yielding the same conclusions regarding overcrowding. When it comes to understaffing, the periods immediately preceding outbreaks were significantly different from both the periods >28/84 days before outbreaks and the outbreak periods, not only the periods >28/84 days before. Other limitations of this study include that the lack of routine screening may have resulted in outbreaks not being recognised, and the different durations of the four periods the outbreak years were divided into. In the 2020–2021 outbreak, for example, the period after the outbreak was only 9 days, which could have affected the result. For this specific outbreak, no consistent pattern of overcrowding or understaffing could be identified. We only collected the number of nurse specialists in relation to two of the four outbreaks, in 2019 and 2020–2021, respectively. This may also represent a limitation of our results and conclusions.

Immunisation, hand hygiene, knowledge, antibiotic stewardship, unit size and single patient rooms are known positive factors related to infection control.[2] The main interventions described in a review were improved infection-control procedures and screening of staff and the environment,[13] all factors that our unit has worked purposefully towards. In addition, we have focused on reducing the number of admissions and length of stay, and optimising basic infection control measures, for example using as little shared equipment as possible and changing gowns between each patient.

5 | CONCLUSION

In conclusion, in our university hospital NICU, bacterial outbreaks in a 5-year period were weakly associated with overcrowding and understaffing. One of the outbreaks was preceded by neither overcrowding nor nurse understaffing, and additional factors are likely to have contributed to bacterial outbreaks in our unit. We speculate that another potential risk factor was more patients needing a higher nurse to patient ratio before and during the outbreaks. Future studies may include stronger research designs, such as Nordic case–control or cohort studies, which our outbreak data might contribute to.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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REFERENCES

1. Doede M, Trinkoff AM, Gurses AP. Neonatal intensive care unit layout and nurses' work. HERD. 2018;11(1):101-118. doi:10.1177/1937586717713734

2. Eriksen HM, Kacelnik O, Sorknes N, Nøkleby H. Situasjonsbeskrivelse av smittevern i Norge. Norwegian Institute of Public Health. Accessed November 10, 2021. https://www.fhi.no/globalassets/dokumenterfiler/notater/2016/situasjonsbeskrivelse-av-smittevern-i-norge-2018-notat-til-hod.pdf
3. Hensel KO, Van den Bruck R, Klare I, Heldmann M, Ghebremedhin B, Jenke AC. Nursing staff fluctuation and pathogenic burden in the NICU – effective outbreak management and the underestimated relevance of non-resistant strains. Sci Rep. 2017;7:45014. doi:10.1038/srep45014
4. Andersen B, Lindemann R, Bergh K, et al. Spread of methicillin-resistant *Staphylococcus aureus* in a neonatal intensive unit associated with understaffing, overcrowding and mixing of patients. J Hosp Infect. 2002;50(1):18-24. doi:10.1053/jhin.2001.1128
5. Norwegian Institute of Public Health. Utbrudd av smittsomme sykdommer – veileder for helsepersonell. Accessed November 10, 2021. https://www.fhi.no/nettpub/smittevernveilederen/temakapitler/06.-utbrudd-av-smittsomme-sykdommer/?term=&h=1
6. Penoyer DA. Nurse staffing and patient outcomes in critical care: a concise review. Crit Care Med. 2010;38(7):1521-1528. doi:10.1097/CCM.0b013e3181e47888
7. Harbarth S, Sudre P, Dharan S, Cadenas M, Pittet D. Outbreak of *Enterobacter cloacae* related to understaffing, overcrowding, and poor hygiene practices. Infect Control Hosp Epidemiol. 1999;20(9):598-603. doi:10.1086/501677
8. Haley RW, Cushion NB, Tenover FC, et al. Eradication of endemic methicillin-resistant *Staphylococcus aureus* infections from a neonatal intensive care unit. J Infect Dis. 1995;171(3):614-624. doi:10.1093/infdis/171.3.614
9. Haley RW, Bregman DA. The role of understaffing and overcrowding in recurrent outbreaks of staphylococcal infection in a neonatal special-care unit. J Infect Dis. 1982;145(6):875-885. doi:10.1093/infdis/145.6.875
10. The Norwegian Directorate of Health. Nasjonal faglig retningslinje for kompetanse og kvalitet i nyfødtintensivavdelinger. The Norwegian Directorate of Health. Accessed November 10, 2021. https://www.helsedirektoratet.no/retningslinjer/nyfodtintensivavdelinger-kompetanse-og-kvalitet
11. Rettedal S, Löhr IH, Natås O, Giske CG, Sundsfjord A, Øymar K. First outbreak of extended-spectrum β-lactamase-producing *Klebsiella pneumoniae* in a Norwegian neonatal intensive care unit; associated with contaminated breast milk and resolved by strict cohorting. APMIS. 2012;120(8):612-621. doi:10.1111/j.1600-0463.2012.02879.x
12. Ohnstad MO. Utfordringer knyttet til bemanning av norske nyfødtavdelinger-en kartleggingsstudie av pasientaktivitet og sykepleiebehov. Master thesis. LDH; 2016.
13. Stapleton PJ, Murphy M, McCallion N, Brennan M, Cunney R, Drew RJ. Outbreaks of extended spectrum beta-lactamase-producing Enterobacteriaceae in neonatal intensive care units: a systematic review. Arch Dis Child-Fetal and Neonatal Ed. 2016;101(1):72-78. doi:10.1136/archdischild-2015-308707
14. Martínez-Aguilar G, Alpuche-Aranda CM, Anaya C, et al. Outbreak of nosocomial sepsis and pneumonia in a newborn intensive care unit by multiresistant extended-spectrum beta-lactamase-producing Klebsiella pneumoniae: high impact on mortality. Infect Control Hosp Epidemiol. 2001;22(11):725-728. doi:10.1017/S019594170007274X
15. Piantadosi S, Byar DP, Green SB. The ecological fallacy. Am J Epidemiol. 1988;127(5):893-904. doi:10.1093/oxfordjournals.aje.a114892

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