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Bacterial Infections in Neonates Following Mupirocin-Based MRSA Decolonization: A Multicenter Cohort Study

Rebecca Pierce, MS, BSN; Kristina Bryant, MD; Alexis Elward, MD, MPH; Justin Lessler, PhD; Aaron M. Milstone, MD, MHS

OBJECTIVE. To characterize the risk of infection after MRSA decolonization with intranasal mupirocin.

DESIGN. Multicenter, retrospective cohort study.

SETTING. Tertiary care neonatal intensive care units (NICUs) from 3 urban hospitals in the United States ranging in size from 45 to 100 beds.

METHODS. MRSA-colonized neonates were identified from NICU admissions occurring from January 2007 to December 2014, during which a targeted decolonization strategy was used for MRSA control. In 2 time-to-event analyses, MRSA-colonized neonates were observed from the date of the first MRSA-positive surveillance screen until (1) the first occurrence of novel gram-positive cocci in sterile culture or discharge or (2) the first occurrence of novel gram-negative bacilli in sterile culture or discharge. Mupirocin exposure was treated as time varying.

RESULTS. A total of 522 MRSA-colonized neonates were identified from 16,144 neonates admitted to site NICUs. Of the MRSA-colonized neonates, 384 (74%) received mupirocin. Average time from positive culture to mupirocin treatment was 3.5 days (standard deviation, 7.2 days). The adjusted hazard of gram-positive cocci infection was 64% lower among mupirocin-exposed versus mupirocin-unexposed neonates (hazard ratio, 0.36; 95% confidence interval [CI], 0.17–0.76), whereas the adjusted hazard ratio of gram-negative bacilli infection comparing mupirocin-exposed and -unexposed neonates was 1.05 (95% CI, 0.42–2.62).

CONCLUSIONS. In this multicentered cohort of MRSA-colonized neonates, mupirocin-based decolonization treatment appeared to decrease the risk of infection with select gram-positive organisms as intended, and the treatment was not significantly associated with risk of subsequent infections with organisms not covered by mupirocin’s spectrum of activity.

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Staphylococcus aureus is the second most common cause of healthcare-associated infections (HAIs) in hospitalized neonates and remains a leading cause of morbidity and excess cost in pediatric settings. Decolonization is a strategy to prevent S. aureus by reducing the bioburden of skin colonization that may otherwise increase risk of subsequent S. aureus infection or transmission. In neonatal intensive care units (NICUs), decolonization primarily has been used to control epidemic and endemic methicillin-resistant S. aureus (MRSA). Mupirocin (pseudomonic acid A), a topical antibiotic, is a widely used decolonizing agent and is typically administered in the nares twice daily for 5 days. Mupirocin is highly active against staphylococci and streptococci, but it has poor in vitro activity against gram-negative bacilli.

Despite calls for more expansive use of mupirocin-based decolonization as a prophylactic infection prevention tool, few studies have evaluated possible unintended consequences of this approach. One potential unintended outcome is pathogen replacement, which is addressed in mupirocin (Bactroban) prescribing information via the caution that application “may result in overgrowth of nonsusceptible microorganisms” but only with prolonged use. Increased susceptibility to infection after systemic antibiotic exposure has been well described in the microbiome literature. Antibiotics may either select for or provide sufficient disruption of the protective microbiota to facilitate infections with other pathogens. There is mounting concern that mupirocin, with its specificity for gram-positive organisms, may facilitate infection with nontargeted, gram-negative pathogens. Gram-negative bacilli are significant NICU pathogens; they are associated with high morbidity and mortality as well as treatment challenges secondary to high-levels of antimicrobial resistance. The possibility of organism replacement after topical antibiotic ointment is particularly salient for infants in
the NICU, as they are subject to recurrent pathogen introduction events from the healthcare setting and are particularly vulnerable to infections due to naive immune systems, a nascent microbiome, poor skin integrity, and frequent use of invasive devices. Our objective was to characterize the intended and unintended outcomes associated with mupirocin use among MRSA carriers in the NICU by estimating (1) the risk of infection with targeted, gram-positive cocci and (2) the risk of infection with nontargeted, gram-negative bacilli.

MATERIALS AND METHODS

Study Design and Population

We conducted a retrospective, multicenter cohort study from January 2007 to December 2014. Data were obtained from 3 tertiary-care NICUs for the portion of the study period when a targeted MRSA decolonization program was employed for MRSA control. Detailed facility data are available in Table 1. We included neonates who were identified as MRSA-colonized by surveillance culture and were, therefore, eligible for decolonization treatment. In addition to decolonization, sites employed other standard elements of NICU infection control practice, including contact precautions for neonates positive for MRSA or other multidrug-resistant organisms and chlorhexidine (CHG) bathing for neonates of higher gestational age (typically >36 weeks).

Definitions and Data Collection

MRSA-colonized neonates were identified via weekly nasal surveillance cultures conducted as part of a targeted decolonization strategy, for which the protocol has been described previously. Neonates entered study observation on the date of first positive MRSA nasal surveillance culture and were followed until outcome occurrence or discharge.

We considered 2 outcomes for 2 separate time-to-event analyses. Outcomes included composites of organisms that were either covered by mupirocin’s spectrum of activity (analysis 1) or were not (analysis 2). In analysis 1, we characterized the occurrence of novel gram-positive cocci in sterile culture. This included staphylococci and streptococci species, organisms covered by mupirocin. In analysis 2, we observed neonates for the occurrence of novel gram-negative bacilli in sterile culture. This outcome included Enterobacteriaceae and other gram-negative rods (eg, Pseudomonas spp. and Acinetobacter spp.) not covered by mupirocin’s spectrum of activity. Outcomes were ascertained from clinical cultures obtained during routine care in the NICU. Sterile sites included blood, urine (obtained from urine catheter), cerebrospinal fluid, abscess fluid, and pleural fluid. Neonates were followed for the novel occurrence of an outcome organism in sterile culture, meaning that neonates were observed only for outcome organism species that had not already been detected in clinical culture prior to study entry. This accounted for the possibility of multiple, distinct infections with organisms of interest during admission and eliminated those that originated prior to study entry. For example, in analysis 2, if a neonate was admitted to the NICU with a Klebsiella pneumoniae-positive clinical culture and subsequently became MRSA colonized, then he or she would be followed for the occurrence of a non-Klebsiella pneumoniae gram-negative organism. Because neonates who had a pre-study-entry positive culture with an outcome organism may have and increased or decreased risk of additional infection with another species within the same outcome type, we included the occurrence of any pre-entry gram-positive cocci or gram-negative bacilli in clinical culture as a potential confounding variable in analysis 1 and analysis 2, respectively. In sensitivity analyses, we restricted our analysis to neonates that were free of all outcome organisms prior to study entry.

Our primary exposure was intranasal mupirocin administration. Mupirocin exposure information was obtained from administrative databases and chart review. A patient was classified as nonexposed from date of first positive MRSA nasal surveillance culture to date of first mupirocin exposure, after which they were considered mupirocin exposed.

Additional sensitivity analyses were performed for each time-to-event analysis to explore the construction of composite outcomes. First, we restricted outcomes to include only bloodstream infections (BSIs) to assess whether our effects were robust when holding the outcome specimen source constant. We additionally conducted a post-hoc sensitivity analysis of time to gram-negative bacilli infection.

### Table 1: Study Site Description

<table>
<thead>
<tr>
<th>Site (City, State)</th>
<th>Calendar Time</th>
<th>Bed Size</th>
<th>Admissions</th>
<th>MRSA-Colonized Neonates</th>
<th>Person Time (Analysis 1)</th>
<th>Person Time (Analysis 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1 (St Louis, MO)</td>
<td>Jan 2007–Dec 2014</td>
<td>75</td>
<td>5,653</td>
<td>233</td>
<td>9,523</td>
<td>9,308</td>
</tr>
<tr>
<td>Site 2 (Louisville, KY)</td>
<td>Aug 2009–Nov 2013</td>
<td>100</td>
<td>4,303</td>
<td>185</td>
<td>5,649</td>
<td>5,932</td>
</tr>
<tr>
<td>Site 3 (Baltimore, MD)</td>
<td>Jan 2007–Dec 2014</td>
<td>45</td>
<td>6,188</td>
<td>104</td>
<td>3,009</td>
<td>3,111</td>
</tr>
<tr>
<td>Total</td>
<td>...</td>
<td>16,144</td>
<td>522</td>
<td>18,181</td>
<td>18,351</td>
<td></td>
</tr>
</tbody>
</table>

*Calendar time refers to the time period during which targeted decolonization was in place for each site. Admissions reflects neonate admissions during the calendar time period. MRSA-colonized neonates identified during the relevant calendar time that had at least one day of follow up were included in the analytic population. Analysis 1 is a survival analysis of time to gram-positive cocci infection and Analysis 2 is a survival analysis of time to gram-negative bacilli infection.
analyses in which we further assessed the impact of character-
izing outcomes with different organism and specimen type
combinations to ensure consistency of results.

Statistical Methods

Bivariate associations between study variables and mupirocin
exposure were assessed using χ², Fisher’s exact, and nonpara-
metric tests. Crude incidence rates were calculated. We con-
ducted survival analyses using Cox proportional hazards
regression to assess differences in the occurrence and timing of
infection by mupirocin receipt. Mupirocin exposure was time
varying as described above. Time at risk was calculated from
the date of first MRSA positive culture to outcome or dis-
charge, resulting in risk set comparisons being among those
with similar time since initial MRSA-colonization and, there-
fore, start of eligibility for mupirocin. A priori confounders of
interest included calendar year, gestational age, birth weight, occurrence of an outcome
organism in culture prior to study entry (described above), and
study site. The proportional hazards assumption was tested by
assessment of Schoenfeld residuals and tests of interaction of
primary study variables with time. Data were analyzed using
STATA v13.1 (StataCorp, College Station, TX) and R v3.2.1
(R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Characteristics of the Study Population

Of 16,144 total neonates admitted to site NICUs throughout the
study period, we identified 522 (3.2%) MRSA-colonized
neonates. Among these, 246 (47%) were female. Race compo-
sition was 59% white, 34% black, and 7% unknown or other.
Mupirocin treatment was administered to 380 (73%) of MRSA-
colonized neonates between first identification of colonization
and discharge or outcome occurrence in analysis 1 and 384
(74%) in analysis 2. Compliance for mupirocin administration
after MRSA-positive surveillance screen ranged by site from 69%
to 79%. Average time to mupirocin receipt among those treated
was 3.5 days (standard deviation, 7.2 days). Distribution of study
variables by mupirocin exposure are presented in Table 2.

Primary Survival Analyses

Overall, 37 novel gram-positive coccii infection events were
detected during the study period, corresponding to an
incidence rate (IR) of 2.0 per 1,000 patient days. The rate of
novel gram-positive coccii infection was 64% lower for mupirocin-exposed neonates than for mupirocin-unexposed
neonates (1.4 vs 3.9 infections per 1,000 patient days;
P = .001). Median follow-up time was 22 days (interquartile
range [IQR], 8–45 days). The adjusted hazard of gram-positive
coxi infection was 64% lower among mupirocin-exposed versus mupirocin-unexposed neonates (HR, 0.36; 95% CI,
0.17–0.76), controlling for length of stay prior to study entry,
calendar year, birth weight, gestational age, study site, and
whether a gram-positive coxi organism had been identified
prior to study entry (Table 3A). Table 2 shows the distribution
of observed gram-positive outcome organisms and sterile
specimen types by mupirocin exposure. Outcomes included
coagulase-negative staphylococci (51%), S. aureus (35%),
streptococci (14%). Blood cultures were the most common
sterile specimen type, accounting for 22 (59%) observed
outcomes.

In total, 29 novel gram-negative bacilli infection events were
observed, corresponding to a rate of 1.6 per 1,000 patient days.
Median follow-up time was 23 days (IQR, 8–49 days). The
crude IR of novel gram-negative bacilli infection was not
significantly different among mupirocin-exposed and -unex-
posed neonates (incidence rate ratio [IRR], 1.19; 95% CI, 0.49–
3.31). Similarly, the adjusted hazard ratio of gram-negative
bacilli infection comparing mupirocin-exposed and mupirocin-
unexposed neonates was 1.05 (95% CI, 0.42–2.62), controlling
for length of stay prior to study entry, calendar year, birth
weight, gestational age, study site, and whether a gram-negative
organism had been identified prior to study entry (Table 3B).
Gram-negative organism and specimen type distribution are
shown in Table 2. Enterobacteriaceae, most notably Klebsiella
spp. (38%), Escherichia coli (21%), and Enterobacter spp. (14%),
were most common. Urine cultures accounted for 21 (72%)
of observed gram-negative bacilli outcomes.

Visual inspection of Schoenfeld residuals and tests of
interaction of mupirocin exposure with time revealed no evi-
dence that the proportional-hazards assumption had been
violated, and no significant time-dependent effects were noted.

Sensitivity Analyses

When restricting to only neonates free of any gram-positive
coccii organisms in clinical culture prior to study entry
(n = 439), the effect of mupirocin exposure on gram-positive
coccii infection risk remained highly protective (HR, 0.30;
95% CI, 0.13–0.66). Mupirocin exposure was associated with a
nonsignificant protective effect on the hazard of gram-negative
bacilli infection among neonates without any gram-negative
bacilli identified prior to study entry (n = 479; HR, 0.81;
95% CI, 0.52–2.03).

Additional sensitivity analyses ensured consistency of results
when restricting the specimen-type and pathogen components
included in composite outcomes. First, outcomes were restric-
ted to those found in blood culture alone. The hazard of gram-
positive coccii BSI was lower among mupirocin-exposed
neonates (HR, 0.37; 95% CI, 0.15–0.88) than in those mupiro-
acin-unexposed, a finding consistent with that for the primary
outcome including all sterile specimen sites. The hazard of BSI
with gram-negative organisms was, again, not significantly dif-
ferent among mupirocin-exposed versus -unexposed neonates
(HR, 0.82; 95% CI, 0.15–4.36). We further assessed the robustness of our findings when altering the organism or
sterile specimen type combinations that defined outcomes.
Results were highly robust irrespective of organism or specimen type, demonstrating a strong protective effect for organisms covered by mupirocin (S. aureus, coagulase-negative staphylococci, streptococci) and hazard ratios that approach 1 for noncovered organisms. Notably, the rate of S. aureus BSI was lower among mupirocin-exposed neonates (IRR = 0.10,
95% CI: 0.01–0.51) as was the hazard of S. aureus BSI in Cox regression analysis (HR = 0.21, 95% CI: 0.04–1.26), though the later was at trend level significance. Additional organisms not covered by mupirocin spectrum activity were included here, including fungi, Propionibacterium spp., enterococci, and Corynebacterium spp. We did not find any evidence of a significant increase in risk of infection when these additional, noncovered organisms were included as outcomes. Results are shown in Supplementary Figure 1.

**DISCUSSION**

Data from this large, multicenter cohort suggest that mupirocin treatment for S. aureus decolonization decreases the risk of infection with select gram-positive organisms. This finding is consistent with other NICU studies that report reduced risk of MRSA or methicillin-sensitive S. aureus after mupirocin treatment.\textsuperscript{19–21} We did not find a statistically significant increase in the risk of infection with gram-negative bacilli among MRSA-colonized NICU patients treated with mupirocin. These findings were robust to the type of sterile specimen source used to identify outcomes.

This study addresses growing concern that decolonization treatment may disrupt the microbiologic ecology of the nares and predispose neonates to infections with other organisms. Gram-negative pathogens are of particular concern as they account for a substantial portion of HAIs in the NICU and are associated with high morbidity and mortality.\textsuperscript{1,14,22} In the current study, we did not observe a significant increase in the proportion, rate, or hazard of gram-negative bacilli infections with mupirocin treatment. In contrast, Perez-Fontan et al.\textsuperscript{23} previously reported an increase of gram-negative infections with nasal mupirocin use in adult peritoneal dialysis patients.\textsuperscript{23} Similarly, the Mupirocin Study Group\textsuperscript{24} conducted a randomized trial of mupirocin use in peritoneal dialysis patients and noted increased occurrence of gram-negative or mixed organism infections. A meta-analysis by van Rijen et al.\textsuperscript{13} pooled data from 3 trials of surgical and peritoneal dialysis patients and found an increased risk of infection with non–S. aureus organisms in those who had received mupirocin treatment. However, adult populations studied to date are likely to be highly distinct from a neonatal population in terms of risk factors, healthcare-associated and outpatient pathogen exposures, as well as microbiome development.

Our study informs distal infectious outcomes associated with mupirocin use as we observed neonates for the duration of their NICU stay, which ranged from days to months. Additional research is needed to assess the more immediate impact of topical antibiotics at the level of the microbiome in hospitalized patients, who may be more susceptible to replacement via repeated exposure to a wide range of healthcare-associated pathogens. Studies of the gut microbiome have shown that antibiotic treatment can disrupt microbial communities and can place recipients at increased risk for colonization with opportunistic pathogens.\textsuperscript{25} However, the impact of disruptions in the skin microbiome following antimicrobial use remains poorly understood,\textsuperscript{26} particularly for the relatively ubiquitous topical antibiotics. Use of triple antimicrobial ointments has been associated with Candida colonization and infection in adult ICU patients.\textsuperscript{27} However, a recent study of 15 adults, both outpatient and ICU patients, found that microbial richness did not differ pre- versus postmupirocin treatment, while S. aureus body-site colonization decreased over time.\textsuperscript{28} The assessment of this issue in neonates remains important because it is possible mupirocin-driven dysbiosis is occurring but is undetectable when clinical infection is the outcome of interest. This factor may be particularly relevant because neonatal microbiomes are evolving and perturbations may impact their long-term composition and stability.

Strengths of our study include the use of data from 3 NICUs that utilize targeted decolonization for MRSA control. The multicentered approach increased the capacity to identify MRSA-colonized and mupirocin-eligible neonates that could
be observed for both intended and unintended infectious outcomes after mupirocin treatment. The longitudinal nature of the data allowed for estimates of individual-level risk of bacterial infections associated with mupirocin use, accounting for time at risk and establishing temporality between exposure and outcomes. In addition, we accounted for the time-varying nature of mupirocin exposure. This was important as mupirocin was not immediately administered in all cases and characterization of this time as mupirocin-exposed would have underestimated the rate of infection, and therefore, also would be underestimated the relative risk of infection associated with mupirocin exposure. The findings of this study support prior work demonstrating that characterization of time-varying antibiotic exposures has important implications for interpreting antimicrobial-associated infection risk.29

Our study has several limitations. First, this was an observational study, and we cannot rule out residual confounding. Although we were not aware of any systematic causes for withheld mupirocin-based decolonization treatment, we attempted to address this issue by comparing only MRSA-colonized neonates at the same time from identification of colonization to maximize comparability between exposure groups. Models were adjusted to control for potential confounders. In particular, adjustment for gestational age, calendar time, and site served to address unit CHG use, secular trends in infection control practice over the study period, and variation in practice by site. Although notable confounding by these variables was not observed, results nevertheless should be interpreted in the context of ongoing, unit-based infection control practices. Postmupirocin infection risk may vary in settings where these practices are not in use. A second limitation is the reliance on clinical culture proxy to define clinically apparent infection outcomes. We limited outcomes to positive bacilli infection risk does not itself demonstrate absence of an effect. To address this issue, we conducted a post-hoc power analysis using effect sizes obtained from the Mupirocin Study Group.24 Given a higher proportion of infection with gram-negative or mixed organisms in the mupirocin group (20 of 134 [15%] vs 7 of 133 [5%]; \(P = .01\) by Fisher’s exact test)24 and our sample size of 522 neonates, our study would have 87% power to detect a similar effect. Further research is required to elucidate the short- and long-term impacts of topical antimicrobials in a neonatal population. Studies that evaluate outcomes associated with decolonization therapy should consider reporting the overall incidence of infections with any organism to assess unintended consequences.

In this study, we report the risk of bacterial infections following mupirocin decolonization in a NICU population. Our analysis suggests that mupirocin-based decolonization treatment does not facilitate infection with organisms not directly targeted by the approach, but it does appear to be working as intended by reducing risk of infection with gram-positive organisms.

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SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/ice.2017.108

REFERENCES