

# High prevalence of antimicrobial resistant Gram negative colonization in hospitalized Cambodian infants

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**Abbreviated title:** Gram Negative Colonization in Cambodian Infants

**Running head title:** Colonization in Cambodian Infants

**Keywords:** colonization; neonate; infant; Gram negative; antimicrobial resistance

**Conflicts of Interest and Sources of Funding:** The authors have no conflicts of interest to declare. This study was funded by a grant from the UK Medical Research Council and Department for International Development (Grant No MR/ K006924/1 to B.S.C.) and by the Wellcome Trust as part of the Wellcome Trust-Mahidol University-Oxford Tropical Medicine Research Programme.

## Background

Antimicrobial-resistant Gram negative infections are a significant cause of mortality in young infants. We aimed to determine characteristics of, and risk factors for, colonization and invasive infection caused by 3<sup>rd</sup> generation cephalosporin (3GC) or carbapenem-resistant organisms in outborn infants admitted to a neonatal care unit (NU) in Cambodia.

## Methods

During the first year of operation, patients admitted to the Angkor Hospital for Children NU underwent rectal swabbing on admission and twice weekly until discharge. Swabs were taken also from 7 environmental sites. Swabs were cultured to identify 3GC or carbapenem-resistant *Acinetobacter* sp., *Escherichia coli*, *Klebsiella pneumoniae*, and *Pseudomonas aeruginosa*.

## Results

The study included 333 infants with a median age at NU admission of 10 days (range 0-43). Colonization by  $\geq 1$  3GC-resistant organism was detected in 85.9% (286/333). Admission swabs were collected in 289 infants: 61.9% were colonized by a 3GC-resistant organism at the time of admission and a further 23.2% were colonized during hospitalization, at a median of 4 days (95% confidence interval (CI) 3-5). Probiotic treatment (hazard ratio 0.58, 95% CI 0.35-0.98) was associated with delayed colonization. Colonization by a carbapenem-resistant organism occurred in 25 (7.5%) infants. Six infants had NU-associated *K. pneumoniae* bacteremia; phenotypically identical colonizing strains were found in three infants. Environmental colonization occurred early.

## Conclusions

Colonization by antimicrobial-resistant Gram negative organisms occurred early in hospitalized Cambodian infants and was associated with subsequent invasive infection. Trials of potential interventions such as probiotics are needed.

## Background

Infection caused by antimicrobial-resistant Gram negative organisms has become a global health concern.<sup>1</sup> In particular, *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Acinetobacter* species have been shown to be important causes of both community-acquired and hospital-acquired sepsis in neonates and infants in low and middle-income countries.<sup>2, 3</sup> These organisms are frequently resistant to multiple antimicrobial classes.<sup>4</sup> Lack of availability of second-line drugs, such as the carbapenems, significantly limits treatment options in resource poor setting and may result in increased mortality from these infections.<sup>5, 6</sup> Recent studies in Asia have highlighted the importance of these organisms in the region, most notably antimicrobial-resistant strains of *K. pneumoniae*.<sup>7, 8</sup> Previously published Cambodian pediatric bloodstream infection data from 2007-2011 demonstrated a high prevalence of 3<sup>rd</sup> generation cephalosporin (3GC) resistance in both community and hospital-acquired *K. pneumoniae* infections.<sup>6</sup> Despite the high burden of disease, little is known about the dynamics of colonization with these organisms amongst infants in low income settings. An understanding of such dynamics is important for the development of urgently needed strategies to contain these organisms.<sup>1, 9</sup>

It is known that colonization of the gastrointestinal tract precedes invasive infection and provides a reservoir of organisms for transmission within the hospital setting.<sup>10-13</sup> Risk factors for acquisition of these organisms in hospital have included prematurity, low birth weight, invasive devices (e.g. feeding tubes), length of stay and antimicrobial exposure.<sup>4, 10, 12, 14, 15</sup> The relative importance of early vertical transmission in neonatal colonization and infection is unknown.<sup>16</sup> Importantly, most previous studies of colonization in neonates and infants have focused on neonatal intensive care units with high proportions of both inborn and premature infants. The prevalence of colonization by resistant Gram negative organisms in neonates and infants admitted to hospital from the community is poorly defined. This is a

1 significant knowledge gap, given that colonization represents a relatively hidden, but easily  
2 studied, reservoir of organisms.  
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4 The aim of the current study was to determine the prevalence and temporal  
5 characteristics of colonization by 3<sup>rd</sup> generation cephalosporin or carbapenem-resistant *K.*  
6 *pneumoniae/oxytoca*, *E. coli*, *P. aeruginosa*, and *Acinetobacter* species in outborn neonates  
7 and infants admitted to a new neonatal care unit in Cambodia, as a prelude to possible  
8 intervention studies.  
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## 19 **Methods**

### 20 ***Study design and participants***

21 The study was carried out at Angkor Hospital for Children (AHC), a non-  
22 governmental paediatric hospital located in Siem Reap, Cambodia. Cambodia has neonatal  
23 and infant mortality rates of 17.6 and 33/1,000 live births, respectively.<sup>17</sup> The hospital  
24 provides secondary and tertiary level care to children 0-15 years of age and has no maternity  
25 unit. The neonatal unit (NU) comprises a high acuity area (neonatal intensive care unit,  
26 NICU) and an adjacent lower acuity area (special care baby unit, SCBU). All NU admissions  
27 were eligible for study enrolment during its first year of operation (11<sup>th</sup> September 2013 - 10<sup>th</sup>  
28 September 2014). Patients could be re-enrolled if they were re-admitted to the NU following  
29 discharge to another ward. Data regarding the antenatal and delivery history; medical care  
30 prior to admission; and clinical, laboratory results, management, and outcome at AHC were  
31 recorded in a case record form. Patients could be given an oral probiotic formulation  
32 (*Lactobacillus acidophilus*; Biorée granules, Daehan NewPharm, Seoul, South Korea) on  
33 admission to reduce the risk of necrotizing enterocolitis at the discretion of the treating  
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Written consent was obtained from mothers prior to study enrolment. The study was reviewed and approved by the AHC Institutional Review Board (1055/13 AHC) and the Oxford Tropical Ethics Committee (1047-13).

### ***Specimens and laboratory assays***

Rectal swabs (Medical Wire and Equipment, Corsham, UK) were obtained from participants within 24 hours of admission and then twice weekly until NU discharge when a final swab was taken. Swabs were placed into Amies transport medium with charcoal and transported immediately to the hospital microbiology laboratory where they were inoculated onto MacConkey agar (Oxoid, Basingstoke, UK). The inoculum was streaked over the plate in four directions to create an even distribution of colonies. Ten microgram cefpodoxime and imipenem disks (Oxoid) were added to the plates prior to overnight incubation in air at 37°C. Cefpodoxime or imipenem-resistant organisms were sub-cultured onto Columbia agar for phenotypic identification of target organisms by Gram stain, oxidase test (Remel, Lenexa, KS), biochemical tests (Triple sugar Iron agar, Urea agar, Citrate agar, Motility-Indole-Lysine agar (Oxoid / BD, Franklin Lakes, NJ)), and API 20E/20NE (bioMerieux, Marcy L'Etoile, France), as appropriate. All non-*A. baumannii* isolates were designated *Acinetobacter* sp. Antimicrobial susceptibilities were done by disk diffusion on Mueller-Hinton agar (Oxoid) following 2013 Clinical and Laboratory Standards Institute (CLSI) criteria.<sup>18</sup> Drugs tested focused on those appropriate for parental treatment of infections in neonates and infants: ampicillin, ceftriaxone, ceftazidime, gentamicin, and imipenem. Intermediate resistance was classified as susceptible in the following analyses, to give a conservative estimate of resistance as MIC data were not available. Extended spectrum beta-lactamase (ESBL) production was determined for *E. coli* and *K. pneumoniae/oxytoca* isolates using the double-disk method (cefotaxime +/- clavulanate and ceftazidime +/- clavulanate (BD)), following CLSI guidelines. Carbapenemase activity was not formally tested in isolates

1 displaying imipenem resistance. Quality control for culture media was done immediately  
2 following preparation of each new batch of plates and antimicrobial discs were tested on a  
3 weekly basis using the appropriate ATCC control strains.  
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7 Clinical culture specimens (i.e. blood cultures) were taken at the discretion of the  
8 treating clinician. Bloodstream infections were defined as community-acquired if the blood  
9 was collected for culture  $\leq 48$  hours of AHC admission and hospital-acquired if collection  
10 was  $>48$  hours after admission.  
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14 Environmental swabs were obtained from 7 sites on the NU at weekly intervals  
15 throughout the study period. The dry swab tip was rotated over the surface of the site before  
16 being placed into transport medium. Swab processing was identical to that described for  
17 rectal swabs.  
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## 20 *Data analysis*

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22 Data were analyzed with the R statistical package version 3.2 (R Foundation for  
23 Statistical Computing, Vienna, Austria). Continuous data were compared using the Wilcoxon  
24 Rank Sum test. Categorical data were compared using the Chi-squared or Fisher's exact test.  
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26 A multivariable logistic regression model was used to predict factors associated with  
27 colonization at first NU admission, and included all variables from the univariable analysis.  
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29 Time to colonization during the first NU admission was assessed using survival analysis and  
30 association with timing of colonization was tested using univariable and multivariable Cox  
31 proportional hazards models. Antimicrobial drug exposures and feeding modalities were  
32 coded as time-varying covariates. Model fit was assessed using the Hosmer-Lemeshow test  
33 and examination of scaled Schoenfeld residuals, as appropriate.  
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### ***Role of the funding source***

The sponsors of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

## **Results**

### ***Study population***

The study included 333 infants. The majority of infants were born at term (279; 83.8%), the median birth weight was 2.8kg (range 0.7-4.5), and 177 (43.2%) were male. All infants were outborn: 160 (48.0%) were born in hospital, 128 (38.4%) in a government health center, 21 (6.3%) at home, and 24 (7.2%) in various other locations. The median age on first admission to the NU was 10 days (0-43) and 323 (97.0%) of first admissions were neonates (aged  $\leq 28$  days). Fifty-five infants (16.5%) had been admitted to another hospital before AHC and 91 (27.3%) were admitted to another ward within AHC before NU admission. The median duration of the first NU admission was 5 days (0-65). Infants were classified as severe (i.e. requiring ventilatory support or inotropes at any point of their AHC admission) in 67 (20.1%) cases. Nineteen (5.7%) infants were admitted to the NU more than once. Six (1.8%) infants died during admission and treatment was withdrawn with the child taken home to die in 4 (1.2%) cases.

A total of 432 blood cultures were taken from 309 of the infants: 297 (68.8%) collected during the NU admission, 112 (25.9%) collected before NU admission, and 23 (5.3%) collected after first NU discharge but before hospital discharge. Significant pathogen(s) were grown from 20 (5.3%) of cultures: 8 (40.0%) were considered community-acquired and 12 (60.0%) were hospital-acquired infections. *Klebsiella pneumoniae* was the commonest organism isolated (7/23 (30.4%) significant isolates) and all were 3GC-resistant

and ESBL positive (Supplemental Digital Content - Table 1). All but 1 (6/7; 85.7%) of the *K. pneumoniae* bloodstream infections were hospital-acquired.

### ***Infant colonization***

A median of 4 (1-22) rectal swabs were collected per infant. Overall, 286 (85.9%) infants were colonized by at least 1 3GC-resistant organism (most commonly *K. pneumoniae/oxytoca* (253; 76.0%)) and 25 (7.5%) were colonized by an imipenem-resistant organism (most commonly *A. baumannii* (19; 6.0%)). Over half (161/286; 56.3%) were colonized by more than 1 3GC-resistant species. *Pseudomonas aeruginosa* colonization was rarely detected, with only 1 infant colonized at a single time-point. ESBLs were detected in almost all 3GC-resistant *E. coli* (555/573; 96.9%) and *K. pneumoniae/oxytoca* (1412/1433; 98.5%). Gentamicin resistance was also common in these organisms, being detected in 89.7% (35/39) of *A. baumannii*, 58.2% (334/574) of *E. coli*, and 57.9% (829/1433) of *K. pneumoniae/oxytoca* isolates.

An admission swab was obtained from 289 infants and a 3GC-resistant target organism was cultured from 179 (61.9%) of these swabs. Colonization at admission did not vary by pre-NU admission status: 62.6% (102/163) in those admitted direct to the NU compared with 60.3% (47/78) in those initially admitted to another AHC department or 62.5% (30/48) in those transferred from another hospital. Of the infants non-colonized on admission, 67 (23.2% of all 289 infants with an admission swab; 60.9% of the 110 infants non-colonized on admission) were subsequently colonized by at least one of the target organisms during the first admission to the NU (Table 1, Supplemental Digital Content - Figure 1). Of the infants who did not have an admission swab, 38/44 (86.4%) were colonized but the timing of first colonization could not be confirmed. In a multivariable logistic



1 regression model, delivery in hospital was associated with colonization on first admission to  
2 the NU (Odds ratio (OR) 3.03, 95% confidence interval (CI) 1.73-5.37) and there was a  
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4 similar trend for those infants born following prolonged rupture of membranes (3.79, 0.99-  
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6 24.97) or having a more severe illness (2.10, 0.96-4.78) (Table 2).  
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10 In the 110 infants known to be colonization free on NU admission, the median time to  
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12 colonization by a 3GC-resistant organism in 67 infants was 4 days (95% CI 3-5) (Figure 1).  
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14 In univariable Cox proportional hazards models, breast milk exposure (hazard ratio (HR)  
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16 0.39, 95% CI 0.18-0.84) and probiotic treatment (0.57, 0.35-0.93) were associated with  
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18 delayed colonization by a 3GC-resistant organism during the first NU admission (Figure 2,  
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20 Table 3). Formula milk exposure was associated with earlier colonization (1.68, 1.03-2.74)  
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22 (Table 3). In the multivariable model, only being probiotic treated (0.58, 0.35-0.98) remained  
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24 associated with delayed colonization. Antimicrobial drug exposure, mostly gentamicin (co-  
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26 administered with ampicillin in 63/66 infants), did not impact timing of colonization (Table  
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34 Rectal swabs were taken pre-blood culture in 4/6 of the infants who had *Klebsiella*  
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36 *pneumoniae* bacteremia during their NU admission: colonizing *K. pneumoniae* with identical  
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38 antibiograms to the blood culture isolate were found in 3 of the infants.  
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#### 41 ***Environmental colonization***

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43 A total of 362 environmental swabs were obtained from 7 sampling locations. One or  
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45 more of the target organisms were isolated from 148 (40.9%) of these swabs. The proportion  
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47 of positive swabs varied by site, from 4.0% (2/50) for the NICU computer keyboard to 96.2%  
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49 (50/52) for the milk kitchen sink (Supplemental Digital Content - Table 2). Environmental  
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51 colonization occurred early. All sites were colonized by 3GC-resistant organisms within 3  
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53 months of the unit opening and 3 (42.9%; dirty utility sink, milk kitchen sink, and isolation  
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55 room sink) were colonized by an imipenem-resistant organism (Supplemental Digital Content  
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- Table 3). Patterns of colonization varied, with the dirty utility and milk kitchen sinks being persistently colonized but the NICU computer keyboard being rarely so (Supplemental Digital Content - Figure 2).

## Discussion

This study has demonstrated the high prevalence of antimicrobial-resistant Gram negative colonization in outborn but hospitalized Cambodian neonates and infants. The new neonatal unit environment was rapidly colonized by the same organisms. In 3/4 cases where it could be assessed, we observed that infants with *K. pneumoniae* bacteremia were colonized by phenotypically identical strains prior to infection onset. Colonization occurred before admission to the neonatal unit in almost two-thirds of infants. Being born in a hospital was associated with a greatly increased risk of early colonization. An association between prolonged rupture of membranes and early colonization suggests that vertical transmission of resistant Gram negative organisms may be responsible for a proportion of early infant colonization, although supporting data for this hypothesis are limited.<sup>16</sup> Treatment with a *Lactobacillus acidophilus*-based probiotic reduced the rate of colonization by over one-third.

Whilst the entirely outborn patient population makes comparison with data from other neonatal units difficult, the factors associated with colonization during NU stay are in broad agreement with data from studies on neonatal units with patient populations dominated by inborn premature infants.<sup>4, 13, 15</sup> However, the overall prevalence of colonization admission was far higher than many previous reports: 86% infants were colonized by at least one 3GC-resistant organism. For example, only 1% of transferred neonates were colonized by antimicrobial-resistant Gram negative organisms on admission to a US NU<sup>19</sup> and 11-24% of Israeli neonates acquired ESBL positive *K. pneumoniae* colonization during NU admission.<sup>20</sup> An Indian study found 97/238 (41%) infants were colonized by ESBL producing *E. coli*

1 during NU admission.<sup>14</sup> In contrast to our findings, a previous non-outbreak related study of  
2 environmental colonization of a new neonatal unit in the USA found a predominance of skin  
3 (e.g. coagulase negative staphylococci) and water-associated organisms (e.g. *P. aeruginosa*);  
4 coliforms and *Acinetobacter* sp. were not identified.<sup>21</sup>  
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10 The potential impact of probiotics on colonization is currently not well defined. There  
11 is increasing evidence that probiotic use in premature neonates reduces the risk of developing  
12 necrotizing enterocolitis.<sup>22</sup> However, a previous small study noted no effect of *L. acidophilus*  
13 on gastrointestinal colonization of premature infants<sup>23</sup> and a recent study on infants with colic  
14 showed no impact of *L. reuteri* on gastrointestinal microbiome diversity.<sup>24</sup> However, on-  
15 going large neonatal studies, including the UK-based PiPS trial of *Bifidobacterium breve*  
16 BBG, will include analyses of impact of probiotics on bloodstream infections and  
17 gastrointestinal colonization by resistant organisms. Recent UK guidelines for management  
18 and prevention of Gram negative infection outbreaks in neonatal units highlighted the need  
19 for research into areas such as the utility of routine surveillance swabs for identification of  
20 colonization / resistance and to determine whether probiotics may affect Gram negative  
21 bacteremia incidence.<sup>25</sup> Given the significant variation in patient populations and  
22 colonization / antimicrobial resistance prevalence, the findings of all such studies would need  
23 to be validated in appropriate low-income settings including those admitting predominantly  
24 outborn infants.  
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46 There were several limitations to our study. A rectal swab was not obtained from the  
47 mothers of participants and thus it was not possible to formally assess the proportion of  
48 colonization that was attributable to vertical transmission. The laboratory methodology used,  
49 although similar to other studies,<sup>10, 12, 26</sup> may have underestimated the prevalence of  
50 colonization. In future studies, the use of chromogenic ESBL or carbapenemase screening  
51 media would be preferable. To further study links between environmental and patient  
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colonization and development of invasive infection, molecular characterization of the isolates would have been desirable and such follow-up work is planned. Finally, the study was conducted in a single site and thus extrapolation of the results to the wider region must be done cautiously. However, the data give important insights into early gastrointestinal colonization by antimicrobial-resistant and disease-associated organisms in neonates and infants from a resource-poor setting with high neonatal and infant mortality.

In conclusion, gastrointestinal colonization by drug-resistant Gram negative organisms occurred early in hospitalized Cambodian neonates and infants and was associated with subsequent invasive infection. We found probiotic use to be associated with a large reduction in the rate of acquisition of these organisms. This association is biologically plausible. Probiotics have not previously been assessed as a potential intervention for reducing acquisition of highly antimicrobial-resistant Gram negative organisms in settings where such organisms are hyper-endemic. In light of our findings we believe assessment of this intervention with randomized trials should be given high priority in such settings.

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## Figure Legends

**Figure 1. Time to colonization by a 3<sup>rd</sup> generation cephalosporin-resistant organism in 110 infants admitted to the neonatal unit and found to be non-colonized on admission**

**Figure 2. The effect of oral probiotic exposure (A) or breast milk consumption (B) on colonization by a 3<sup>rd</sup> generation cephalosporin-resistant organism in 110 infants admitted to the neonatal unit and found to be non-colonized on admission**

Forty five of the infants were given a *Lactobacillus acidophilus*-containing oral probiotic formulation as part of their clinical management. Ninety seven infants received breast milk.



**Table 1. Colonization by antimicrobial-resistant *Acinetobacter baumannii*/sp., *Escherichia coli*, and *Klebsiella pneumoniae/oxytoca* in 333 hospitalised Cambodian young infants**

Organism	Time point first colonized, n (%)					
	At NU* admission		During NU stay(s)		Unknown time point†	
	289 infants				44 infants	
	3GC-R‡	IPM-R‡	3GC-R	IPM-R	3GC-R	IPM-R
<i>E. coli</i>	97 (33.6)	1 (0.3)	60 (20.8)	2 (0.7)	26 (59.1)	0 (0.0)
<i>K. pneumoniae/oxytoca</i>	121 (41.9)	0 (0.0)	96 (33.2)	2 (0.7)	32 (72.7)	0 (0.0)
<i>A. baumannii</i> /sp.	11 (3.8)	10 (3.5)	5 (1.7)	5 (1.7)	4 (9.1)	4 (9.1)
<i>P. aeruginosa</i>	0 (0.0)	0 (0.0)	1 (0.3)	0 (0.0)	0 (0.0)	0 (0.0)
Any target organism	179 (61.9)	11 (3.8)	67 (23.2)	9 (3.1)	38 (86.4)	4 (9.1)

\*NU: neonatal unit

†Unable to define timing of colonization due to missing admission swab

‡3GC-R: 3<sup>rd</sup> generation cephalosporin-resistant; IPM-R: imipenem-resistant (+/- 3<sup>rd</sup> generation cephalosporin-resistant)

**Table 2. Results of univariable and multivariable logistic regression models exploring factors associated with colonization by 3<sup>rd</sup> generation cephalosporin-resistant *A. baumannii*/sp., *E. coli*, *K. pneumoniae/oxytoca*, or *P. aeruginosa* on first admission to the neonatal unit for 289 infants**

Factor	Infants (n)	Colonization by a 3GC*-resistant organism, OR (95% CI)			
		Univariable analysis	P-value	Multivariable analysis	P-value
Prematurity (<37/40)	47	0.89 (0.45 – 1.79)	0.7	0.70 (0.31 – 1.54)	0.4
PROM (>18 hours)†	16/261‡	4.67 (1.03 – 42.98)	0.03	3.79 (0.99 – 24.97)	0.09
Birth location					
<i>Health Centre</i>	109	0.41 (0.24 – 0.68)	<0.001	-	-
<i>Home</i>	20	1.15 (0.41 – 3.53)	0.8	2.17 (0.73 – 6.99)	0.2
<i>Hospital</i>	144	2.28 (1.36 – 3.83)	0.001	3.03 (1.73 – 5.37)	<0.001
<i>Other</i>	16	1.03 (0.33 – 3.54)	1.0	1.91 (0.61 – 6.69)	0.3
Severe (ventilated, CPAP**, or inotropes)	57	1.42 (0.74 – 2.81)	0.3	2.10 (0.96 – 4.78)	0.07
Admitted to another department or hospital pre-NU††	126	0.94 (0.57 – 1.56)	0.8	0.79 (0.44 – 1.40)	0.4

\* 3<sup>rd</sup> generation cephalosporin-resistant

† PROM: prolonged rupture of membranes

‡ Denominator reflects missing data

\*\* CPAP: continuous positive airway pressure

†† NU: neonatal unit

**Table 3. Results of univariable and multivariable Cox proportional hazards models to define factors affecting time to colonization by a 3<sup>rd</sup> generation cephalosporin-resistant *A. baumannii*/sp., *E. coli*, *K. pneumoniae/oxytoca*, or *P. aeruginosa* isolate in 110 infants admitted to the neonatal unit and found to be non-colonized on admission**

Factor	Infants (n)	Univariable model		Multivariable model	
		HR (95% CI)	P-value	HR (95% CI)	P-value
Prematurity (<37/40)	19	0.80 (0.45 – 1.42)	0.4	0.64 (0.34 – 1.22)	0.2
Breast milk (before / during NU* admission)	97	0.39 (0.18 – 0.84)	0.02	0.53 (0.22 – 1.25)	0.1
Formula milk (in hospital)	42	1.68 (1.03 – 2.74)	0.04	1.44 (0.82 – 2.53)	0.2
Probiotic treatment	45	0.57 (0.35 – 0.93)	0.03	0.58 (0.35 – 0.98)	0.04
Severe (ventilated, CPAP†, or inotropes)	18	1.39 (0.75 – 2.58)	0.3	1.69 (0.81 – 3.55)	0.2
Admitted to another department or hospital pre-NU	49	1.49 (0.92 – 2.42)	0.1	1.34 (0.79 – 2.28)	0.3
Ceftriaxone treatment	3	0.83 (0.20 – 3.44)	0.8	0.83 (0.20 – 3.47)	0.8
Gentamicin treatment‡	66	1.51 (0.87 – 2.64)	0.1	1.30 (0.73 – 2.32)	0.4
Imipenem treatment	9	0.66 (0.32 – 1.37)	0.3	0.51 (0.22 – 1.19)	0.1

\*NU: neonatal unit

† CPAP: continuous positive airway pressure

‡Administered with ampicillin in 63/66 cases

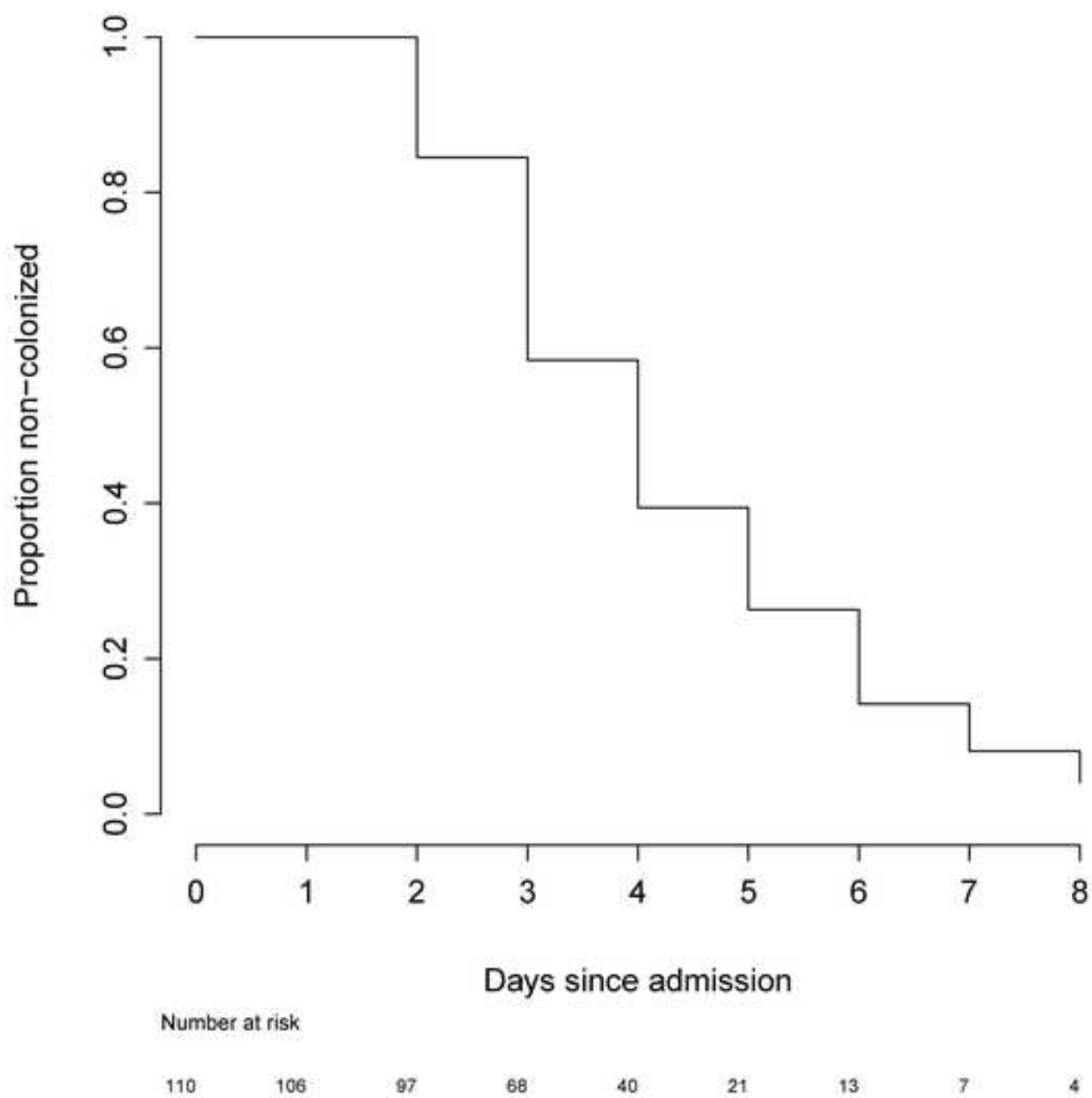
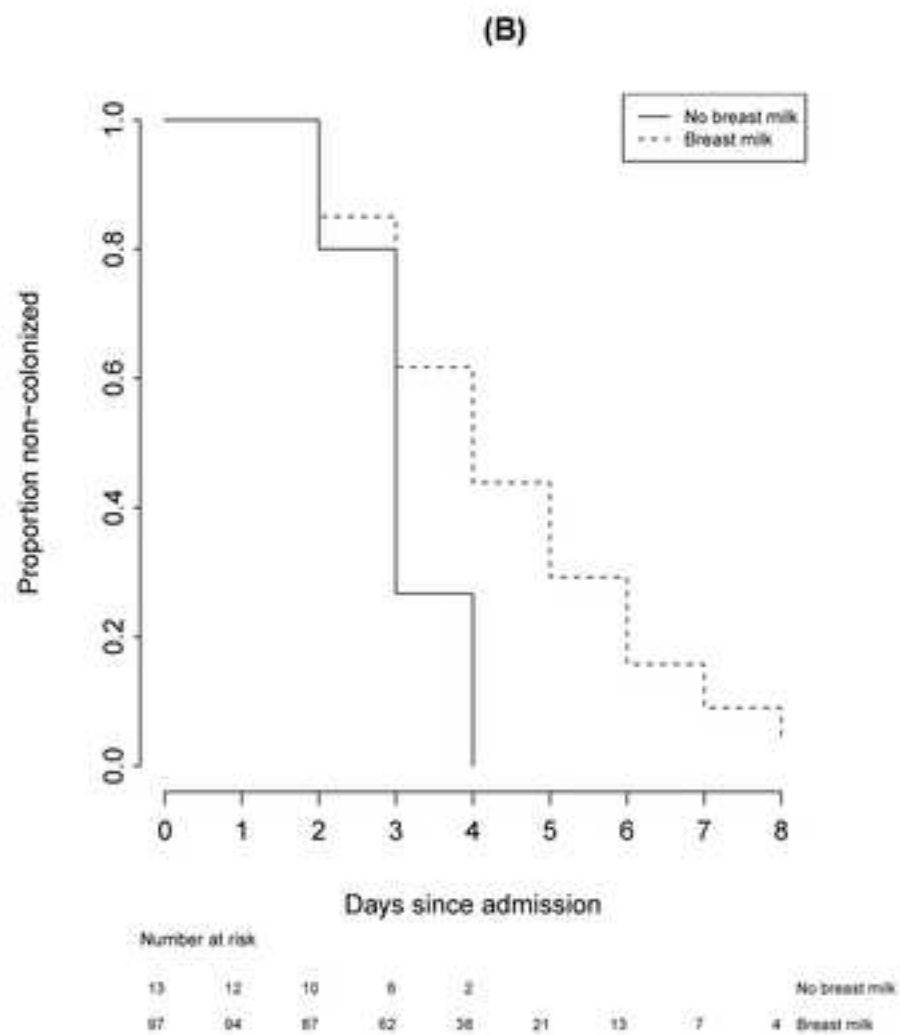
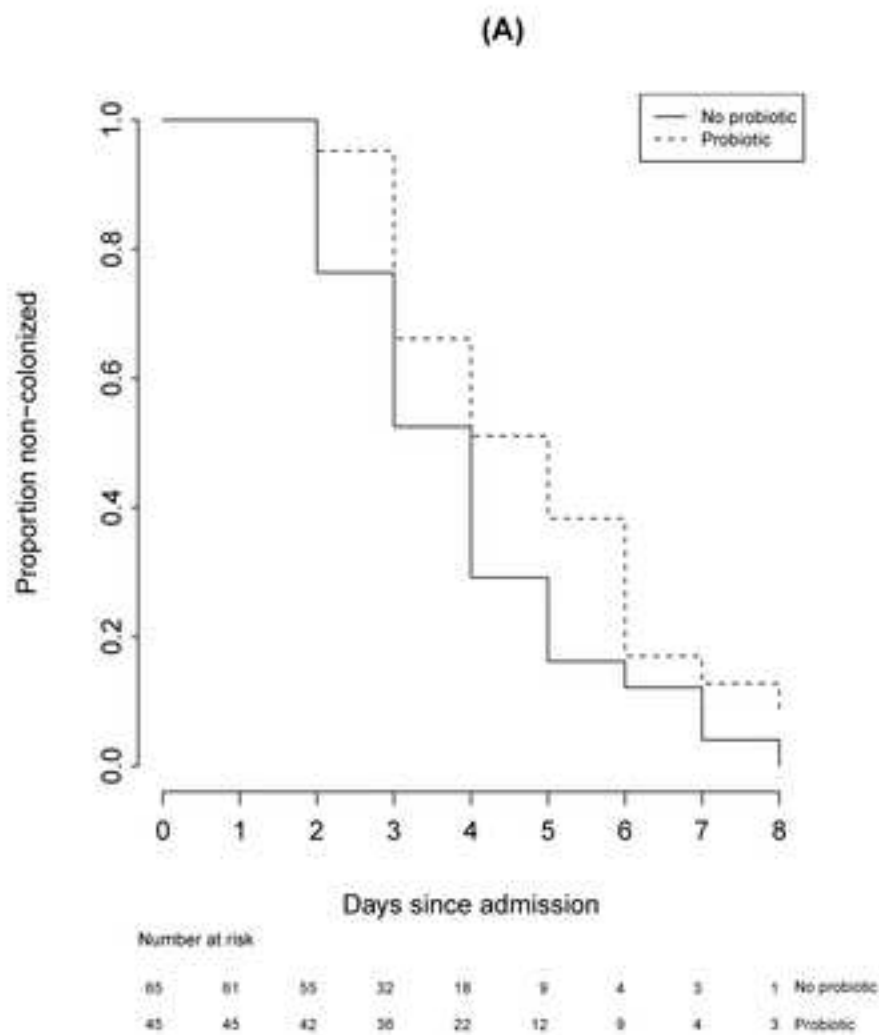


Figure 2



## Supplemental Digital Content

### High prevalence of antimicrobial resistant Gram negative colonization in hospitalized Cambodian infants

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#### SDC Table 1. Bacterial isolates from 432 blood cultures collected from 309 infants admitted to the neonatal unit, by timing of infection and organism

Twenty cultures grew a significant pathogen and 3 of these cultures were polymicrobial (2 organisms identified) resulting in a total of 23 isolates

Organism	Pre-NU*		NU		Post-NU		Total, n (%)
	CAI†	HAI†	CAI	HAI	CAI	HAI	
<i>Acinetobacter baumannii</i>	0	0	0	1	0	0	1 (4.3)
<i>Acinetobacter</i> sp.	0	0	0	1	0	0	1 (4.3)
<i>Enterobacter cloacae</i>	0	0	0	3	0	0	3 (13.0)
<i>Enterococcus</i> sp.	1	0	0	0	0	0	1 (4.3)
<i>Escherichia coli</i>	0	1	2	0	0	0	3 (13.0)
<i>Klebsiella pneumoniae</i>	1	0	0	6	0	0	7 (30.4)
<i>Moraxella catarrhalis</i>	1	0	0	0	0	0	1 (4.3)
<i>Serratia liquifaciens</i>	0	1	0	0	0	0	1 (4.3)
<i>Serratia marcescens</i>	0	0	0	1	0	1	2 (8.7)
<i>Staphylococcus aureus</i>	0	0	1	0	0	0	1 (4.3)
<i>Streptococcus pyogenes</i>	1	0	1	0	0	0	2 (8.7)
Total, n (%)	4 (17.4)	2 (8.7)	4 (17.4)	12 (52.2)	0 (0.0)	1 (4.3)	23

\*NU: neonatal unit

†CAI: community acquired infection; HAI: hospital-acquired infection

**SDC Table 2. Proportion of neonatal unit environmental swabs positive, by site and organism**

Site	Total swabs	Target organism*, n (%)				
		As	Ec	Kp	Pa	Any
Dirty utility sink	52	15 (28.8)	5 (9.6)	43 (82.7)	0	45 (86.5)
Entrance sink	52	6 (11.5)	3 (5.8)	7 (13.5)	0	14 (26.9)
Isolation room sink	52	4 (7.7)	2 (3.8)	12 (23.1)	0	17 (32.7)
Milk kitchen sink	52	5 (9.6)	0	47 (90.4)	0	50 (96.2)
NICU keyboard†	50	0	0	2 (4.0)	0	2 (4.0)
NICU sink	52	1 (1.9)	0	5 (9.6)	0	6 (11.5)
SCBU sink†	52	2 (3.8)	1 (1.9)	11 (21.2)	0	14 (26.9)
Total	362	33	11	127	0	148

\*As: *Acinetobacter baumannii*/sp.; Ec: *Escherichia coli*; Kp: *Klebsiella pneumoniae/oxytoca*; Pa: *Pseudomonas aeruginosa*;  
Any: any of the 4 target organisms

†NICU: high acuity area (neonatal intensive care unit); SCBU: low acuity area (special care baby unit)

**SDC Table 3. Time to neonatal unit environmental colonization, by site and antimicrobial resistance phenotype**

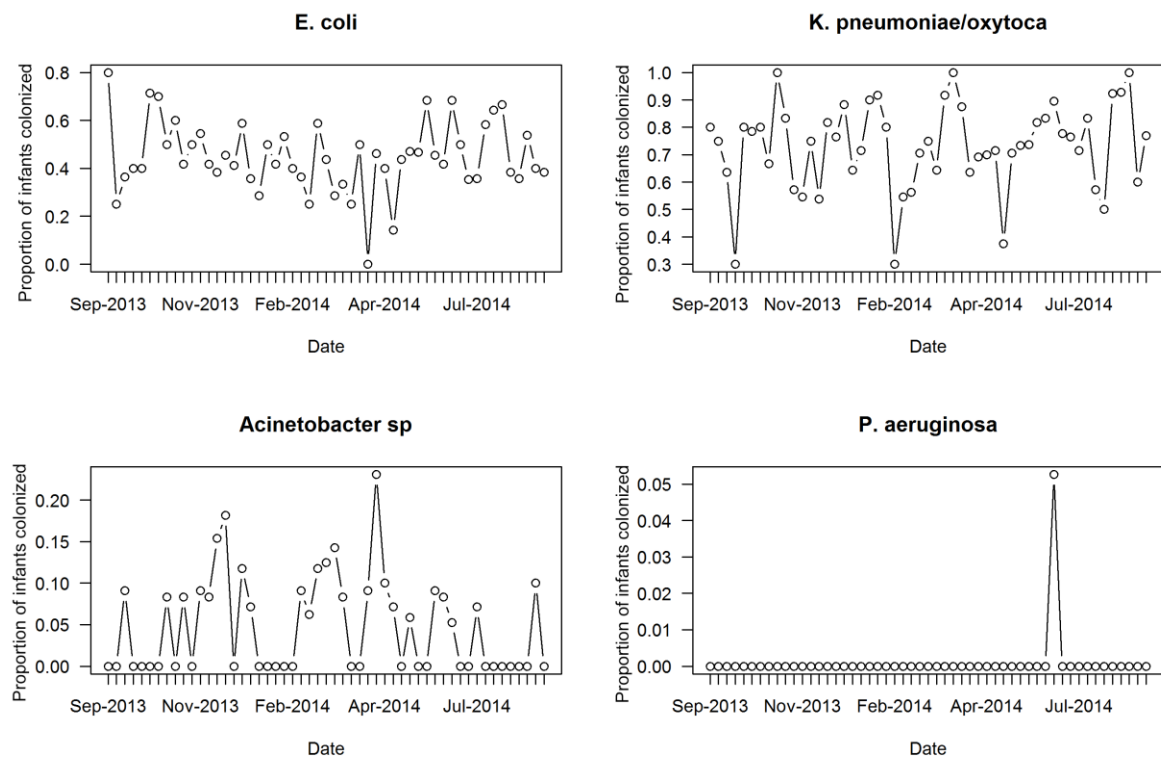
Site	Time to colonization (days)	
	3GC-resistant organism*	IPM-resistant organism*
Dirty utility sink	14	71
Entrance sink	71	NC
Isolation room sink	35	182
Milk kitchen sink	7	21
NICU keyboard†	91	NC
NICU sink	28	NC
SCBU sink†	28	NC

\*3GC: 3<sup>rd</sup> generation cephalosporin; IPM: imipenem; NC: not colonized

†NICU: high acuity area (neonatal intensive care unit); SCBU: low acuity area (special care baby unit)



**SDC Figure 1. Proportion of infants colonized, by target organism and study week**



**SDC Figure 2. Patterns of environmental colonization by 3<sup>rd</sup> generation cephalosporin or carbapenem-resistant Gram negative organisms on the neonatal unit, 2013-14**

NICU: high-acuity area (neonatal intensive care unit); SCBU: low-acuity area (special care baby unit)

