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The clinical features, antimicrobial susceptibility patterns, and genomics of bacteria causing neonatal sepsis in a children's hospital in Vietnam: protocol for a prospective observational study

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Manuscripts

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3 1 **The clinical features, antimicrobial susceptibility patterns, and genomics of bacteria causing**
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5 2 **neonatal sepsis in a children's hospital in Vietnam: protocol for a prospective observational**
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7 3 **study**
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48 24 **Running title:** Vietnam neonatal sepsis protocol
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3 25 **Abstract**

4 26 **Introduction:** The clinical syndrome of neonatal sepsis, comprising signs of infection, septic shock,
5 27 and organ dysfunction in infants ≤ 4 weeks of age, is a frequent sequel to bloodstream infection and
6 28 mandates urgent antimicrobial therapy. Bacterial characterisation and antimicrobial susceptibility
7 29 testing is vital for ensuring appropriate therapy, as high rates of antimicrobial resistance (AMR),
8 30 especially in low and middle-income countries (LMICs), may adversely affect outcome. Ho Chi Minh
9 31 City (HCMC) in Vietnam is a rapidly expanding city in Southeast Asia with a current population of
10 32 almost 8 million. There are limited contemporary data on the causes of neonatal sepsis in Vietnam,
11 33 and we hypothesize, that the emergence of multi-drug resistant bacteria is an increasing problem for
12 34 the appropriate management of sepsis cases. In this study, we aim to investigate the major causes of
13 35 neonatal sepsis and assess disease outcomes by clinical features, antimicrobial susceptibility profiles,
14 36 and genome composition.

15 37 **Method and analysis:** We will conduct a prospective observational study to characterize the clinical
16 38 and microbiological features of neonatal sepsis in a major children's hospital in HCMC. All bacteria
17 39 isolated from blood subjected to whole genome sequencing. We will compare clinical variables and
18 40 outcome between different bacterial species, genome composition and AMR gene content. AMR gene
19 41 content will be assessed and stratified by species, year, and contributing hospital department. Genome
20 42 sequences will be analysed to investigate phylogenetic relationships.

21 43 **Ethics and dissemination:** The study will be conducted in accordance with the principles of the
22 44 Declaration of Helsinki and the International Council on Harmonization Guidelines for Good Clinical
23 45 Practice. Ethics approval has been provided by the Oxford Tropical Research Ethics Committee and
24 46 Children's Hospital 1. The findings will be disseminated at international conferences and peer-
25 47 reviewed journals.

26 48 **Trial registration:** ISRCTN69124914

27 49 **Ethics references:** Oxford (Oxford Tropical Research Ethics Committee 35-16), Vietnam (Children's
28 50 Hospital 1 Ethics Committee 73/GCN/BVND1)

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3 53 **Strengths and limitations of this study**

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5 54 • Little is known about the current aetiological agents of neonatal sepsis in Vietnam; the clinical
6
7 55 and microbiological information generated by this study will inform local clinical practice and
8
9 56 guidelines.
- 10
11 57 • This prospective study aims to integrate clinical assessments with microbiological and detailed
12
13 58 whole genome sequence data to accurately and comprehensively characterize the aetiology and
14
15 59 outcome of neonatal sepsis in this high mortality setting.
- 16
17 60 • Limitations to the study include ethical issues involved in collecting samples from severely ill
18
19 61 neonates, lack of systematic guidelines ensuring accurate and transferable definitions of clinical
20
21 62 phenotype are used, stochastic variations in numbers of cases collected due to seasonal variation
22
23 63 and continuous changes in community antimicrobial and vaccine use.
- 24
25 64 • This study is being performed at the largest secondary/tertiary paediatrics centre in Southern
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27 65 Vietnam, data collection at a single site may limit the applicability to other hospitals in the
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29 66 country.
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67 **Background**

68 Neonatal sepsis is widely recognized as a clinical syndrome of systemic inflammation in response to,
69 or occurring the same time as, a possible or proven infection (frequently by identifying bacterial
70 bloodstream infection) occurring in children ≤ 28 days of age. A consensus definition of neonatal
71 sepsis has remained a challenge.(1) Globally, the incidence of neonatal sepsis is estimated to be 1–5
72 cases/1,000 live births but is lower in full-term neonates (1–2 cases/1,000 live births), in whom the
73 incidence is higher in males than females.(2,3) Early-onset sepsis is defined as the start of sepsis
74 symptoms within 72 hours of birth,(1,4) and is often caused by vertical transmission of pathogens
75 during delivery as a result of chorioamnionitis or maternal genital tract colonization.(5) Late-onset
76 sepsis, occurring after 72 hours from birth,(1,6) may be caused by similar vertical transmission or
77 horizontal transmission mechanisms, due to direct contact with the surrounding environment,
78 attendant healthcare staff, or any invasive procedures.(7)

80 *Neonatal sepsis in Southeast Asia*

81 Neonatal sepsis remains a leading cause of neonatal hospital admission, morbidity, and mortality in
82 lower and middle income countries (LMICs).(8) In this setting, bacterial infection, including
83 bacteraemia, is complicated by multidrug resistance, particularly related to healthcare acquired
84 infection, and effective management of neonatal sepsis is increasingly problematic.(8) Recently, the
85 World Health Organization (WHO) has acknowledged the problem of AMR as an endemic and
86 widespread problem in LMICs.(9) In many LMICs untreatable bacterial infections with broadly AMR
87 pathogens are no longer a threat but a common reality. AMR in LMICs represents one of the biggest
88 threats to global health, and are one of the greatest current challenges in infectious disease research.

89
90 While AMR is an issue with all types of bacterial infection, the issue is most acute in management of
91 clinical sepsis. This is a particular problem in neonates, due to high mortality/morbidity rates and the
92 timely need for rapid detection and treatment of the causative pathogen. Sepsis demonstrates
93 extensive geographical diversity in both aetiology and proportions of AMR bacteria isolated.(10,11)
94 Understanding the local and regional epidemiology of sepsis in hospitalized neonates is crucial in the

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3 95 development of rational management and treatment guidelines, especially in high-risk AMR LMICs
4 96 locations like Vietnam.

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9 98 ***Sepsis and AMR in Vietnam***

10 99 Bacterial sepsis is classified into two major groups according to place of acquisition. Hospital-
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12 100 acquired sepsis is defined in patients with clinical manifestations of sepsis and a confirmatory blood
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14 101 culture collected >48 hours following hospital admission.(12) Hospital-acquired sepsis is a major
15
16 102 threat to patient safety, and in locations with poor surveillance and infection control programs such
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18 103 infections are associated with high mortality rates. The incidence of AMR bloodstream infections in
19
20 104 Vietnam has increased over recent years, and is predicted to increase further.(13) This trend has
21
22 105 comprised an increase in both Gram-negative and Gram-positive pathogens, chiefly *Escherichia coli*,
23
24 106 *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Staphylococcus aureus*, and enterococci.

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28 108 Community-acquired sepsis is also an important cause of fever among patients admitted to hospitals
29
30 109 across South and Southeast Asia. In our practice, community-acquired sepsis is defined as the
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32 110 presence of sepsis with a confirmatory blood culture collected within 48 hours after hospital
33
34 111 admission.(14) Distinguishing bacterial infections from other common causes of fever, such as
35
36 112 malaria or dengue, can be challenging without diagnostic laboratory support.(15) Important causes of
37
38 113 community-acquired bloodstream infection (CA-BSI) in LMICs include *Salmonella* serovars Typhi
39
40 114 and Paratyphi A, *E. coli*, *K. pneumoniae*, *S. aureus* and *S. pneumoniae*. We have reported increasing
41
42 115 levels of AMR in these common community-acquired pathogens and highlighted the difficulties of
43
44 116 accurate diagnosis with traditionally available diagnostics. For example in Nepal and Vietnam
45
46 117 antimicrobial resistance in *Salmonella* Typhi and *Salmonella* Paratyphi A has severely restricted the
47
48 118 options available for antimicrobial treatment.(16)

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52 120 ***The changing aetiology of BSI in Vietnam***

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54 121 The aetiology of CA-BSI in Vietnam has changed considerably over the 20 years. A previous study
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56 122 documented the decline of *Salmonella* Typhi from 2002, the predominant pathogen until this point,

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3 123 and the subsequent increase in non-typhoidal *Salmonella* and other opportunistic HIV-associated
4 124 pathogens.(17) This shift is likely to reflect a changing landscape of infectious disease related to the
5 125 HIV epidemic, urbanization, and secondary social determinants within Vietnam. Vietnam, as with
6
7 126 many countries in Asia, is undergoing a rapid economic transition, and programmes to improve
8
9 127 sanitary conditions have reduced the overall risk of water-borne infections. HIV-associated
10
11 128 opportunistic pathogens have now emerged as the leading cause of bloodstream infections and the
12
13 129 primary cause of mortality in hospitalized adult patients in this location. These studies were
14
15 130 performed at the Hospital for Tropical diseases in Ho Chi Minh City and thus included mainly adults,
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17 131 including those with HIV, and children but not neonates.(18–20) Therefore, these observations may
18
19 132 not be fully representative of the situation in neonates.
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134 ***Knowledge gaps***

135 Little is known about contemporary antimicrobial susceptibility patterns and their underlying genetic
136 determinants in the major causes of neonatal bacterial of sepsis in Vietnam. Furthermore, the impact
137 of antimicrobial susceptibility and other virulence factors on disease progression and outcome in
138 neonates in LMICs is also not well documented. To address these issues, we aim to investigate the
139 aetiology of pathogens associated with bacterial sepsis in neonates and to detail the effects of reduced
140 antimicrobial susceptibility on the outcome of sepsis in neonates. This will be a clinical and
141 microbiology laboratory research project between Children's Hospital 1 and the Oxford University
142 Clinical Research Unit in Vietnam. This study will be a conduit for introducing molecular biology for
143 bacteriology into routine hospital care this children's hospital and will lead to future studies
144 investigating appropriate empirical treatment for bacteraemia and the impact of antimicrobial
145 resistance on the outcome of sepsis in the paediatric and neonatal population in Vietnam.

146

147 **Rationale, aim and objectives**

148 To understand the causes of neonatal sepsis and to best inform antimicrobial treatment regimes in our
149 setting we will perform a prospective observational study at Children's Hospital 1 in Vietnam from
150 2017 to 2019. There are limited contemporary data on the causes of bacterial sepsis in neonates in

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3 151 Vietnam. We hypothesize that there have been recent increases in multi-drug resistant Gram-negative
4
5 152 bacteria causing sepsis in this high-risk group, and that methicillin-resistant *Staphylococcus aureus*
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7 153 (MRSA) has emerged as an important pathogen. We further aim to investigate the clinical features,
8
9 154 major causes of neonatal sepsis, and the distribution of pathogens by department, their antimicrobial
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11 155 susceptibility patterns and the genomic profiles of the isolated bacteria as well as their association
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13 156 with disease outcomes.
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17 158 **Primary objectives**

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19 159 • To describe the clinical characteristics of neonates with sepsis, including community and
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21 160 hospital-acquired sepsis, early and late-onset sepsis.
22
23 161 • To determine the aetiology of neonatal sepsis and the distribution of pathogens by clinical
24
25 162 department including the Neonatology Department and the Neonatal Intensive Care Unit.
26
27 163 • To determine the antimicrobial susceptibility profiles of the bacteria causing neonatal sepsis
28
29 164 and the AMR profiles occurring in community and hospital-acquired infections.
30
31 165 • To analyse the impact of specific bacteria and AMR profile on the outcomes (mortality,
32
33 166 length of stay and cost of treatment) of neonates with sepsis.
34
35 167 • To determine the genome sequences of bacterial strains associated with neonatal sepsis
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39 169 **Secondary objectives**

- 40
41 170 • To determine the AMR profiles and gene distribution of isolated bacteria by clinical
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43 171 departments to add insight into the circulation of bacteria associated with hospital acquired
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45 172 infections.
46
47 173 • To study the genes catalysing resistance to antimicrobials commonly used to treat neonatal
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49 174 sepsis (specifically third/fourth generation cephalosporins, fluoroquinolones and
50
51 175 carbapenems).
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178 **Methods**

179 ***Study design***

180 This protocol describes a prospective, non-interventional, observational study to characterize the
181 clinical features of neonates with sepsis at Children's Hospital 1 in Ho Chi Minh City in Vietnam
182 between 2017 and 2019, the microbial population structure, antimicrobial susceptibility patterns and
183 the AMR genes of the bacteria causing that sepsis. All organisms isolated from blood will be stored
184 and archived for molecular characterization.

185

186 ***Study sites***

187 Children's Hospital 1 (Neonatology Department, Neonatal Intensive Care Unit, Microbiology
188 Department) in Ho Chi Minh City in Vietnam. The estimated population of the city was 8.4 million in
189 2016, and 23.8% are children 0-14 years of age.(21) Children's Hospital 1 is the largest tertiary
190 paediatrics centre in Southern Vietnam with 1,400 inpatient beds and >1,600 staff members. The
191 hospital receives ~1.5 million outpatient visits and 95,000 admissions each year. Care is provided to
192 all children <15 years old from Ho Chi Minh City and other provinces of Southern Vietnam. The
193 neonatal centre at CH1 currently has 120 inpatient beds for the neonatology department and additional
194 30 beds in the neonatal intensive care unit. The overall mean rate of positive blood cultures in our
195 hospital is 7% per year.

196

197 **Definitions**

198 ***Definition of sepsis***

199 A sepsis episode in this study is defined as isolation of a clinically relevant pathogen from ≥ 1 blood
200 culture, drawn from a neonate with ≥ 1 clinical or laboratory sign of sepsis (Table 1).(22)

201

202 ***Diagnosis of neonatal sepsis***

203 Systematic guidelines concerning which patients should have blood cultures performed are not strictly
204 defined in our hospital, although blood culture results are used to confirm the diagnosis of sepsis in
205 neonates with a compatible clinical presentation. We use the criteria suggested by the European

206 Medicines Agency (EMA) in 2010 for the diagnosis of “probable sepsis” and “confirmed sepsis” in
207 neonates:(22)

- 208 • Probable sepsis: ≥ 2 clinical and ≥ 2 laboratory signs.
- 209 • Confirmed sepsis: ≥ 1 positive culture of a pathogen and ≥ 1 clinical or laboratory sign.

211 **Sample size**

212 In this prospective observational study, we aim to recruit all patients with available data who fulfil the
213 inclusion criteria and are admitted to Children’s Hospital 1 in Ho Chi Minh City in Vietnam from
214 2017 – 2019. Based on retrospective surveillance data, we estimate recruitment of 800 participants
215 during the study period. Blood cultures will be performed in all cases, we expect to yield ~400
216 bacterial isolates.

218 **Participant selection and recruitment**

219 ***Inclusion criteria***

220 Neonates (≤ 1 month of age) with a diagnosis of “probable” or “confirmed” sepsis who have had a
221 blood culture taken and who are an in-patient at Children’s Hospital 1 will be recruited into the study,
222 after written informed consent has been given by a parent or guardian.

223 ***Exclusion criteria***

224 Patients will be excluded when informed consent is not provided, the length of hospital stay less than
225 24 hours, imminent and inevitable death, or the patient has been previously recruited in the study.

226 ***Identification of participants***

227 All doctors and nurses in the Department of Neonatology, Neonatal Intensive Care Unit and
228 Microbiology Department of the study hospital will be informed about, and trained for, this clinical
229 investigation. In addition, those working in the microbiology department, neonatology department,
230 and neonatal intensive care unit will also be informed and involved in the study. These staff will be
231 trained to identify eligible patients and how to notify investigators.

233 **Informed consent**

234 Trained, GCP-accredited, members of the study team will collect informed consent. The team will
235 discuss the study with the accompanying parent/guardian, or, if both parents are deceased or not
236 actively involved in child care, the main long-term carer of the child will be accepted as the guardian
237 and considered able to give consent for the study. Study staff will describe the purpose of the study,
238 the study procedures, possible risks/benefits, the rights and responsibilities of participants, and
239 alternatives to enrolment. The parent/guardian will be invited to ask questions, which will be
240 addressed by study staff, and they will be provided with appropriate contact numbers if they have any
241 subsequent questions. If the parent/guardian agrees for the child to participate, they will be asked to
242 sign and date an informed consent form. A copy of the patient information sheet and the informed
243 consent form will be given to them to keep. In addition to the procedures above, illiterate signatories
244 will have the Informed Consent Form read to them in the presence of a witness who will sign to
245 confirm this. All patient information sheets and consent forms will be written in the local language
246 and will use terms that are easily understandable.

248 **Study procedures**

249 An investigator will routinely record and collect demographic, clinical and laboratory information of
250 the patients, the date of blood draw, the number of blood culture bottles inoculated, the result of the
251 culture (whether positive or negative) and the susceptibility of the isolate to commonly used
252 antimicrobials. Data from these records will be subsequently entered into CliRes Data Management
253 System of Oxford University Clinical Research Unit. These will be source data for this study. The
254 number of patients admitted to the hospital annually will be obtained from hospital records. As part of
255 this study we request that all isolates from blood are stored and archived at -80°C . These isolates will
256 be re-cultured and the identification will be re-confirmed. Selected isolated organisms from blood will
257 have further molecular characterization at a later date.

259 **Data collection**

260 *Demographic and clinical assessments*

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3 261 Data on neonatal sepsis at Children's Hospital 1 will be collected to the case report form. These data
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5 262 will include administrative data, demographic data, clinical characteristics, laboratory results,
6
7 263 diagnoses, treatments and outcomes. The Neonatal Therapeutic Intervention Scoring System (NTISS)
8
9 264 will be used to estimate the disease severity.(23)

10 265

11 266 ***Microbiological assessments***

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14 267 Available routine microbiology data on neonatal bloodstream infections Children's Hospital 1. These
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16 268 data will include pathogenic agents isolated from blood culture and antimicrobial susceptibility profile
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18 269 of isolated bacteria (routine panel of antimicrobials). Selected isolates will have additional
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20 270 antimicrobial susceptibility testing, molecular analysis for antimicrobial resistance genes and genome
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22 271 sequencing of selected strains defined by antimicrobial susceptibility data.
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25 273 **Laboratory methods**

26 274 ***Microbiology testing***

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28 275 When required for checking or to non-routine antimicrobials, antimicrobial susceptibility testing of
29
30 276 the pathogens isolated will be performed by disk diffusion using guidelines established by the Clinical
31
32 277 and Laboratory Standards Institute (CLSI) and, when required, by minimum inhibitory concentration
33
34 278 estimation (MIC) using the VITEK 2 COMPACT automated machine. Antimicrobial susceptibilities
35
36 279 tested will include nalidixic acid, ciprofloxacin, ceftriaxone, cefepime, ampicillin, trimethoprim-
37
38 280 sulfamethoxazole, azithromycin, imipenem, colistin and amikacin for all Gram-negative organisms
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40 281 and oxacillin and vancomycin in Gram-positive organisms. The production of extended-spectrum beta
41
42 282 lactamases (ESBL) will be investigated using the double-disc synergy test by comparing zone sizes
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44 283 between ceftazidime discs against ceftazidime-clavulanic acid discs and cefotaxime discs against
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46 284 cefotaxime-clavulanic acid discs. Isolates with an increase in diameter of inhibitory zone of equal to
47
48 285 or more than 5 mm by the synergy of clavulanate will be considered ESBL positive.
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50 286 ***Bacterial storage***

51 287 Organisms will be sub-cultured onto 5% blood agar and the purity of the isolate will be tested before
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53 288 storage in 20% glycerol at -80°C.
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5 290 ***Isolation of nucleic acids***

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7 291 Isolates will be re-cultured and their identification re-checked. DNA will be extracted from bacterial
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9 292 isolates using the Wizard Genomic DNA Extraction Kit (Promega, Fitchburg, USA). The quality and
10
11 293 concentration of the DNA will be assessed using a nano-drop spectrophotometer prior to PCR
12
13 294 amplification and the Quant-IT Kit (Invitrogen, Carlsbad, CA) prior to DNA sequencing.

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17 296 ***PCR for resistance genes***

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19 297 The primary focus study is to investigate the distribution of antimicrobial resistance genes in bacteria
20
21 298 causing neonatal sepsis. Therefore, all Gram-negative organisms will be investigated by PCR to
22
23 299 detect genes catalyzing resistance to cephalosporins, fluoroquinolones and carbapenems.

24
25 300 Conventional PCR will be performed for the following classes of resistance genes using previously
26
27 301 described methods. The multiplex and monoplex PCRs are described in these publications. This panel
28
29 302 of PCRs will be used; PCR1 - AmpC (MOX-1, MOX-2, CMY-1, CMY8-11), PCR2 - AmpC (LAT-1
30
31 303 to LAT-4, CMY2-7, BIL-1), PCR3 - AmpC (DHA1 and DHA-2), PCR4 - AmpC (ACC), PCR5 -
32
33 304 AmpC (MIR-1T, ACT-1), PCR6 - AmpC (FOX-1-5b), PCR7 - ESBL (CTX-M1), PCR8 - ESBL
34
35 305 (CTX-M2), PCR9 - ESBL (CTX-M9), PCR10 - ESBL (CTX-M8/M25), PCR11 - ESBL (TEM),
36
37 306 PCR12 - ESBL (SHV), PCR13 - ESBL (OXA1, 4, 30), PCR13 - qnrA, B, S, and PCR13 - gyrA, B, C,
38
39 307 PCR14 - NDM-1, PCR 15 - mecA/Van.(11,24-29)

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41 30842
43 309 ***Genome sequencing***

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45 310 Selected organisms (on the basis of their susceptibility profiles and resistance gene content) will be
46
47 311 genome sequenced. We aim to sequence the greatest cross-section of organism groups as possible (i.e.
48
49 312 all *Staphylococci* or all *Klebsiella*). Selected bacterial isolates will be sequenced at Oxford University
50
51 313 Clinical Research Unit in Vietnam. Briefly, index-tagged paired end Illumina sequencing libraries
52
53 314 will be prepared using one of 96 unique indexing tags as previously described. These will be
54
55 315 combined into pools of uniquely tagged libraries and sequenced on the Illumina Genome Analyzer or

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3 316 HiSeq sequencer according to manufacturer's protocols to generate tagged 54-100 bp paired-end
4 317 reads. This is a previously described for Gram-negative organisms and *Staphylococcus*.(20,30,31)

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8 319 **Analysis plan**

9 320 ***Statistical comparisons***

10 321 Data will be presented in the form of tables and bar charts for descriptive variables i.e. number of
11
12 322 organisms per year and number of AMR organisms per year. Statistical comparisons of features
13
14 323 between groups (positive/negative blood culture, Gram negative/Gram positive bacteria, survival/non-
15
16 324 survival etc.). Time trend analysis of the cultured isolates by month and the antimicrobial
17
18 325 susceptibility patterns will be determined. All statistical analysis will be performed using Stata
19
20 326 version 14 (Stata Corp LP, College Station, TX, USA) and R. P-values of ≤ 0.05 will be considered
21
22 327 significant.
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28 329 ***Antimicrobial resistance genes and genome sequencing***

29 330 The presence/absence of antimicrobial resistance genes will be reported as proportions per organism
30
31 331 and then stratified by organism, year, and hospital department. Genome sequences will be determined
32
33 332 to study phylogenetic relationships, the presence/absence of virulence genes and also AMR gene
34
35 333 content and firstly analysed by species and then group by their Gram-stain results. Briefly, for
36
37 334 phylogenetic analysis, chromosomal Single Nucleotide Polymorphism (SNP) alleles will be
38
39 335 concatenated for each strain to generate a multiple alignment of all SNPs. For maximum likelihood
40
41 336 (ML) analysis, RAxML will be run using the generalized time-reversible model and one thousand
42
43 337 bootstrap pseudo-replicate analyses were performed to assess support for the ML phylogeny. Root-to-
44
45 338 tip branches will be extracted from the ML tree using the program TreeStat. The relationship between
46
47 339 root-to-tip distances and year of isolation will be analyzed using linear regression. For BEAST
48
49 340 analysis (v1.6), a GTR+ Γ substitution model and defined tip dates, as the date of isolation will be
50
51 341 used.(30–32) To detect the presence or absence of genes read sets will be assembled using the *de novo*
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53 342 short read assembler Velvet and Velvet Optimizer. Organism specific read sets will then be aligned to
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3 343 the pan-genome. Taxonomic investigation of accessory and AMR genes will be performed using MG-
4 344 RAST v3.2.

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9 346 **Ethics, regulatory approvals and governance**

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11 347 This study is sponsored by the University of Oxford and will be monitored by the Clinical Trials Unit
12 348 at Oxford University Clinical Research Unit (OUCRU). The Principal Investigator (SB) will ensure
13 349 that this study is conducted in accordance with the principles of the Declaration of Helsinki and the
14 350 terms of approval of the appropriate ethical committees.(33) The study will be conducted in full
15 351 conformity with relevant regulations and with the International Council on Harmonization (ICH)
16 352 Guidelines for Good Clinical Practice (GCP).(34) This protocol and the relevant supporting document
17 353 have already had the approvals of the Oxford Tropical Research Ethics Committee (OxTREC) and the
18 354 institutional review board (IRB) of Children's Hospital 1. The investigators will submit and, where
19 355 necessary, obtain approval from the above parties for all substantial amendments to the original
20 356 approved documents.

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32 358 **Dissemination and public engagement**

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34 359 Data from this study will be of interest to the scientific and clinical research communities. An
35 360 informative resource for managing sepsis will be made available to local clinicians, clinical
36 361 microbiologists and infection control policy developers. Study data will be reported according to the
37 362 STROBE guidance for reporting observational studies.(35) The authors (and their respective positions
38 363 in the author list) will be agreed prior to the start of the study in accordance with the guidelines of the
39 364 International Committee of Medical Journal Editors. In line with Wellcome Trust policy that the
40 365 results of publicly-funded research should be freely available, manuscripts arising from this study will
41 366 be submitted to peer-reviewed journals which enable Open Access. In line with research transparency
42 367 and greater access to data sharing policy of OUCRU in Vietnam will be implemented. This policy is
43 368 based on a controlled access approach with a restriction on data release that would compromise an on-
44 369 going trial or study. Data exchange complies with Information Governance and Data Security Policies
45 370 in all of the relevant countries.

371

372 Discussion

373 As a conduit for introducing molecular biology for bacteriology into routine hospital care in Vietnam
374 the study is unique, and is planned to lead to future studies investigating appropriate empirical
375 treatment for bacteraemia and the impact of AMR on the outcome of sepsis in the neonatal and
376 paediatric population in Vietnam. By studying and defining disease aetiology, antimicrobial
377 susceptibility patterns and disease outcome we plan to develop an improved approach to managing
378 bloodstream infections in our setting and we will use these data to initiate intervention studies focused
379 on preventing sepsis with AMR pathogens in neonates.

380

381 Duration and current status of study

382 The first patient was recruited in January 2017. At the current time the recruitment is on-going. The
383 expected end date for recruitment is 31 December 2019. We expect to have completed our data
384 analysis plan with a view of results by June 2020.

385

386 Authors' contributions

387 All authors satisfy the criteria for authorship as per the ICMJE 'Recommendations for the Conduct,
388 Reporting, Editing, and Publication of Scholarly Work in Medical Journals'. (36) NDT, TCD, CJB,
389 JIC, AK, EK, LQT, NKM, PTTT, LNTN, NNQM, CNP, NTH, NMX, TCT and SB contributed to the
390 conception and design of the study. NDT, TCD and SB drafted the protocol of the study. This article
391 was drafted by NDT, TCD and SB. CJB, JIC, AK, EK, LQT, NKM, PTTT, LNTN, NNQM, CNP,
392 NTH, NMX, TCT, NDT, TCD and SB read and critically revised the protocol and this article prior to
393 submission.

394

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401

402 **Competing interests**

403 All authors have no competing interests to declare.

404

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538 **Table 1. Clinical and laboratory signs of neonatal sepsis**

Clinical signs of sepsis	<ul style="list-style-type: none"> • Abnormal body temperature (core temperature $>38.5^{\circ}\text{C}$ or $<36^{\circ}\text{C}$ and/or temperature instability) • Cardiovascular instability (bradycardia [mean heart rate $<10^{\text{th}}$ percentile for age in the absence of external vagal stimulus, beta-blockers or congenital heart disease or otherwise unexplained persistent depression over a 0.5–4h time period] or tachycardia [mean heart rate $>2\text{SD}$ above normal for age in the absence of external stimulus, chronic unexplained persistent elevation over a 0.5–4h time period] and/or rhythm instability, reduced urinary output ($<1\text{ mL/kg/h}$), hypotension (mean arterial pressure $<5^{\text{th}}$ percentile for age), mottled skin, impaired peripheral perfusion) • Respiratory instability (apnea episodes or tachypnea episodes [mean respiratory rate $>2\text{SD}$ above normal for age] or increased oxygen requirements or requirement for ventilator support) • Gastrointestinal (feeding intolerance, poor sucking, abdominal distension) • Skin and subcutaneous lesions (petechial rash, sclerema) • Non-specific (irritability, lethargy, hypotonia)
Laboratory signs of sepsis	<ul style="list-style-type: none"> • White blood cells $<4 \times 10^9\text{ cells/L}$ or $>20 \times 10^9\text{ cells/L}$ • Immature to total neutrophil ratio (I/T) >0.2 • Platelet count $<100 \times 10^9\text{/L}$ • CRP $>15\text{ mg/L}$ or Procalcitonin $\geq 2\text{ ng/mL}$ • Glucose intolerance (hyperglycemia [blood glucose $>180\text{ mg/dl}$ or 10 mmol/L] or hypoglycemia [blood glucose $<45\text{ mg/dl}$ or 2.5 mmol/L]) • Metabolic acidosis (base excess $<-10\text{ mEq/L}$ or serum lactate $>2\text{ mmol/L}$)

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545 **Table 2. Study summary**

Title	The clinical features, antimicrobial susceptibility patterns and genomics of bacteria causing neonatal sepsis in a children's hospital in Vietnam
Design	Observational prospective study All organisms isolated from blood will be stored and archived for molecular characterization
Participants	Neonates (≤ 1 month of age) with sepsis
Planned Enrolment Period	2017 – 2019
Primary Objectives	<ul style="list-style-type: none"> • To investigate the clinical characteristics of neonatal sepsis. • To define the aetiology, the percentage of positive blood culture and major causes of sepsis. • To investigate the antimicrobial susceptibilities of the pathogens causing sepsis and the rate of antimicrobial resistance. • To measure the impact of sepsis on the severity of disease and the outcomes (mortality rate, length of stay and cost of treatment) of hospitalized neonates. • To analyse the genome sequences of bacterial strains causing neonatal sepsis.
Secondary Objectives	<ul style="list-style-type: none"> • To analyse the antimicrobial resistance profiles and gene distribution by clinical departments to add insight into the circulation of bacteria causing nosocomial infections. • To study the genes catalysing resistance to the antimicrobials commonly used to treat neonatal sepsis (specifically third/fourth generation cephalosporins, fluoroquinolones and carbapenems).

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BMJ Open

The clinical features, antimicrobial susceptibility patterns, and genomics of bacteria causing neonatal sepsis in a children's hospital in Vietnam: protocol for a prospective observational study

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Primary Subject Heading:	Paediatrics
Secondary Subject Heading:	Infectious diseases, Genetics and genomics
Keywords:	Sepsis, Neonates, Clinical features, Antimicrobial resistance, Genomics, Outcomes

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3 **The clinical features, antimicrobial susceptibility patterns, and genomics of bacteria causing**
4 **neonatal sepsis in a children's hospital in Vietnam: protocol for a prospective observational**
5 **study**
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48 **Running title:** Vietnam neonatal sepsis protocol
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Abstract

Introduction: The clinical syndrome of neonatal sepsis, comprising signs of infection, septic shock, and organ dysfunction in infants ≤ 4 weeks of age, is a frequent sequel to bloodstream infection and mandates urgent antimicrobial therapy. Bacterial characterisation and antimicrobial susceptibility testing is vital for ensuring appropriate therapy, as high rates of antimicrobial resistance (AMR), especially in low and middle-income countries (LMICs), may adversely affect outcome. Ho Chi Minh City (HCMC) in Vietnam is a rapidly expanding city in Southeast Asia with a current population of almost 8 million. There are limited contemporary data on the causes of neonatal sepsis in Vietnam, and we hypothesize, that the emergence of multi-drug resistant bacteria is an increasing problem for the appropriate management of sepsis cases. In this study, we aim to investigate the major causes of neonatal sepsis and assess disease outcomes by clinical features, antimicrobial susceptibility profiles, and genome composition.

Method and analysis: We will conduct a prospective observational study to characterize the clinical and microbiological features of neonatal sepsis in a major children's hospital in HCMC. All bacteria isolated from blood subjected to whole genome sequencing. We will compare clinical variables and outcomes between different bacterial species, genome composition and AMR gene content. AMR gene content will be assessed and stratified by species, years, and contributing hospital departments. Genome sequences will be analysed to investigate phylogenetic relationships.

Ethics and dissemination: The study will be conducted in accordance with the principles of the Declaration of Helsinki and the International Council on Harmonization Guidelines for Good Clinical Practice. Ethics approval has been provided by the Oxford Tropical Research Ethics Committee and Children's Hospital 1. The findings will be disseminated at international conferences and peer-reviewed journals.

Trial registration: ISRCTN69124914

Ethics references: Oxford (Oxford Tropical Research Ethics Committee 35-16), Vietnam (Children's Hospital 1 Ethics Committee 73/GCN/BVND1)

Strengths and limitations of this study

- Little is known about the current aetiological agents of neonatal sepsis in Vietnam; this prospective study will integrate clinical assessments with microbiological and detailed whole genome sequence data to characterize the aetiology and outcome of neonatal sepsis in this high mortality setting.
- This study is being performed at the largest secondary/tertiary paediatrics centre in Southern Vietnam; data collection at a single site may limit the applicability to other hospitals in the country.
- Other limitations encountered in designing this study include ethical issues involved in collecting samples from severely ill neonates, lack of current transferable definitions for neonatal sepsis phenotypes, and stochastic variations in numbers of cases recruited due to seasonal variation and continuous changes in community antimicrobial and vaccine use.
- Some contamination of blood cultures is unavoidable in our setting and therefore accurately classifying some isolates as true pathogens in certain cases may be challenging.

Background

Neonatal sepsis is widely recognized as a clinical syndrome of systemic inflammation in response to, or occurring the same time as, a possible or proven infection (frequently by identifying bacterial bloodstream infection) occurring in children ≤ 28 days of age. A consensus definition of neonatal sepsis has remained a challenge.(1) Globally, the incidence of neonatal sepsis is estimated to be 1–5 cases/1,000 live births but is lower in full-term neonates (1–2 cases/1,000 live births), in whom the incidence is higher in males than females.(2,3) Early-onset sepsis is defined as the start of sepsis symptoms within 72 hours of birth,(1,4) and is often caused by vertical transmission of pathogens during delivery as a result of chorioamnionitis or maternal genital tract colonization.(5) Late-onset sepsis, occurring after 72 hours from birth,(1,6) may be caused by similar vertical transmission or horizontal transmission mechanisms, due to direct contact with the surrounding environment, attendant healthcare staff, or any invasive procedures.(7)

Neonatal sepsis in Southeast Asia

Neonatal sepsis remains a leading cause of neonatal hospital admission, morbidity, and mortality in lower and middle income countries (LMICs).(8) In this setting, bacterial infection, including bacteraemia, is complicated by multidrug resistance, particularly related to healthcare acquired infection, and effective management of neonatal sepsis is increasingly problematic.(8) Recently, the World Health Organization (WHO) has acknowledged the problem of AMR as an endemic and widespread problem in LMICs.(9) In many LMICs untreatable bacterial infections with broadly AMR pathogens are no longer a threat but a common reality. AMR in LMICs represents one of the biggest threats to global health, and are one of the greatest current challenges in infectious disease research.

While AMR is an issue with all types of bacterial infection, the issue is most acute in management of clinical sepsis. This is a particular problem in neonates, due to high mortality/morbidity rates and the timely need for rapid detection and treatment of the causative pathogen. Sepsis demonstrates extensive geographical diversity in both aetiology and proportions of AMR bacteria isolated.(10,11) Understanding the local and regional epidemiology of sepsis in hospitalized neonates is crucial in the

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3 development of rational management and treatment guidelines, especially in high-risk AMR LMICs
4 locations like Vietnam.
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8 ***Sepsis and AMR in Vietnam***

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10 Bacterial sepsis is classified into two major groups according to place of acquisition. Hospital-
11 acquired sepsis is defined in patients with clinical manifestations of sepsis and a confirmatory blood
12 culture collected >48 hours following hospital admission.(12) Hospital-acquired sepsis is a major
13 threat to patient safety, and in locations with poor surveillance and infection control programs such
14 infections are associated with high mortality rates. The incidence of AMR bloodstream infections in
15 Vietnam has increased over recent years, and is predicted to increase further.(13) This trend has
16 comprised an increase in both Gram-negative and Gram-positive pathogens, chiefly *Escherichia coli*,
17 *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Staphylococcus aureus*, and enterococci.
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28 Community-acquired sepsis is also an important cause of fever among patients admitted to hospitals
29 across South and Southeast Asia. In our practice, community-acquired sepsis is defined as the
30 presence of sepsis with a confirmatory blood culture collected within 48 hours after hospital
31 admission.(14) Distinguishing bacterial infections from other common causes of fever, such as
32 malaria or dengue, can be challenging without diagnostic laboratory support.(15) Important causes of
33 community-acquired bloodstream infection (CA-BSI) in LMICs include *Salmonella* serovars Typhi
34 and Paratyphi A, *E. coli*, *K. pneumoniae*, *S. aureus* and *S. pneumoniae*. We have reported increasing
35 levels of AMR in these common community-acquired pathogens and highlighted the difficulties of
36 accurate diagnosis with traditionally available diagnostics. For example in Nepal and Vietnam
37 antimicrobial resistance in *Salmonella* Typhi and *Salmonella* Paratyphi A has severely restricted the
38 options available for antimicrobial treatment.(16)
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51 ***The changing aetiology of BSI in Vietnam***

52 The aetiology of CA-BSI in Vietnam has changed considerably over the 20 years. A previous study
53 documented the decline of *Salmonella* Typhi from 2002, the predominant pathogen until this point,
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3 and the subsequent increase in non-typhoidal *Salmonella* and other opportunistic HIV-associated
4 pathogens.(17) This shift is likely to reflect a changing landscape of infectious disease related to the
5 HIV epidemic, urbanization, and secondary social determinants within Vietnam. Vietnam, as with
6 many countries in Asia, is undergoing a rapid economic transition, and programmes to improve
7 sanitary conditions have reduced the overall risk of water-borne infections. HIV-associated
8 opportunistic pathogens have now emerged as the leading cause of bloodstream infections and the
9 primary cause of mortality in hospitalized adult patients in this location. These studies were
10 performed at the Hospital for Tropical diseases in Ho Chi Minh City and thus included mainly adults,
11 including those with HIV, and children but not neonates.(18–20) Therefore, these observations may
12 not be fully representative of the situation in neonates.
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24 ***Knowledge gaps***

25 Little is known about contemporary antimicrobial susceptibility patterns and their underlying genetic
26 determinants in the major causes of neonatal bacterial of sepsis in Vietnam. Furthermore, the impact
27 of antimicrobial susceptibility and other virulence factors on disease progression and outcome in
28 neonates in LMICs is also not well documented. To address these issues, we aim to investigate the
29 aetiology of pathogens associated with bacterial sepsis in neonates and to detail the effects of reduced
30 antimicrobial susceptibility on the outcome of sepsis in neonates. This will be a clinical and
31 microbiology laboratory research project between Children's Hospital 1 and the Oxford University
32 Clinical Research Unit in Vietnam. This study will be a conduit for introducing molecular biology for
33 bacteriology into routine hospital care at this children's hospital and will lead to future studies
34 investigating appropriate empirical treatment for bacteraemia and the impact of antimicrobial
35 resistance on the outcome of sepsis in the paediatric and neonatal population in Vietnam.
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50 **Rationale, aim and objectives**

51 To understand the causes of neonatal sepsis and to best inform antimicrobial treatment regimes in our
52 setting we will perform a prospective observational study at Children's Hospital 1 in Vietnam from
53 2017 to 2019. There are limited contemporary data on the causes of bacterial sepsis in neonates in
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3 Vietnam. We hypothesize that there have been recent increases in multi-drug resistant Gram-negative
4 bacteria causing sepsis in this high-risk group, and that methicillin-resistant *Staphylococcus aureus*
5 (MRSA) has emerged as an important pathogen. We further aim to investigate the clinical features,
6 major causes of neonatal sepsis, and the distribution of pathogens by departments, their antimicrobial
7 susceptibility patterns and the genomic profiles of the isolated bacteria as well as their association
8 with disease outcomes.
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15 16 17 **Primary objectives**

- 18 • To describe the clinical characteristics of neonates with sepsis, including community and
19 hospital-acquired sepsis, early and late-onset sepsis.
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- 21 • To determine the aetiology of neonatal sepsis and the distribution of pathogens by clinical
22 departments including the Neonatology Department and the Neonatal Intensive Care Unit.
23
- 24 • To determine the antimicrobial susceptibility profiles of the bacteria causing neonatal sepsis
25 and the AMR profiles occurring in community and hospital-acquired infections.
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- 27 • To analyse the impact of specific bacteria and AMR profile on the outcomes (mortality,
28 length of stay and cost of treatment) of neonates with sepsis.
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- 30 • To determine the genome sequences of bacterial strains associated with neonatal sepsis.
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38 39 **Secondary objectives**

- 40 • To determine the AMR profiles and gene distribution of isolated bacteria by clinical
41 departments to add insight into the circulation of bacteria associated with hospital acquired
42 infections.
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- 44 • To study the genes catalysing resistance to antimicrobials commonly used to treat neonatal
45 sepsis (specifically third/fourth generation cephalosporins, fluoroquinolones and
46 carbapenems).
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Methods

Study design

This protocol describes a prospective, non-interventional, observational study to characterize the clinical features of neonates with sepsis at Children's Hospital 1 in Ho Chi Minh City in Vietnam between 2017 and 2019, the microbial population structure, antimicrobial susceptibility patterns and the AMR genes of the bacteria causing that sepsis. All organisms isolated from blood will be stored and archived for molecular characterization.

Study site

Children's Hospital 1 (Neonatology Department, Neonatal Intensive Care Unit, Microbiology Department) is in Ho Chi Minh City in Vietnam. The estimated population of the city was 8.4 million in 2016, and 23.8% are children 0-14 years of age.(21) Children's Hospital 1 is the largest tertiary paediatrics centre in Southern Vietnam with 1,400 inpatient beds and >1,600 staff members. The hospital receives ~1.5 million outpatient visits and 95,000 admissions each year. Care is provided to all children <15 years old from Ho Chi Minh City and other provinces of Southern Vietnam. The neonatal centre at this hospital currently has 120 inpatient beds for the neonatology department and additional 30 beds in the neonatal intensive care unit. The overall mean rate of positive blood cultures in our hospital is 7% per year.

Definitions

Definition of sepsis

A sepsis episode in this study is defined as isolation of a clinically relevant pathogen from ≥ 1 blood culture, drawn from a neonate with ≥ 1 clinical or laboratory sign of sepsis (Table 1).(22)

Diagnosis of neonatal sepsis

Systematic guidelines concerning which patients should have blood cultures performed are not strictly defined in our hospital, although blood culture results are used to confirm the diagnosis of sepsis in neonates with a compatible clinical presentation. We use the criteria suggested by the European

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3 Medicines Agency (EMA) in 2010 for the diagnosis of “probable sepsis” and “confirmed sepsis” in
4 neonates:(22)

- 5 • Probable sepsis: ≥ 2 clinical and ≥ 2 laboratory signs.
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- 7 • Confirmed sepsis: ≥ 1 positive culture of a pathogen and ≥ 1 clinical or laboratory sign.
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10 11 12 **Sample size**

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14 In this prospective observational study, we aim to recruit all patients with available data who fulfil the
15 inclusion criteria and are admitted to Children’s Hospital 1 in Ho Chi Minh City in Vietnam from
16 2017 – 2019. Based on retrospective surveillance data, we estimate recruitment of 800 participants
17 during the study period. Blood cultures will be performed in all cases, we expect to yield ~400
18 bacterial isolates.
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25 26 **Participant selection and recruitment**

27 ***Inclusion criteria***

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29 Neonates (≤ 1 month of age) with a diagnosis of “probable” or “confirmed” sepsis who have had a
30 blood culture taken and who are an in-patient at Children’s Hospital 1 will be recruited into the study,
31 after written informed consent has been given by a parent or guardian.
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36 ***Exclusion criteria***

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38 Patients will be excluded when informed consent is not provided, the length of hospital stay less than
39 24 hours, imminent and inevitable death, or the patient has been previously recruited in the study.
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41 Investigators will review all of the mortality records during the time period of the study to try and
42 identify how many of these cases may have been missed and whether there were any common
43 characteristics in these participants.
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48 ***Identification of participants***

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50 All doctors and nurses in the Department of Neonatology and Neonatal Intensive Care Unit of the
51 study hospital will be informed about, and trained for, this clinical investigation. In addition, those
52 working in the Department of Neonatology and Neonatal Intensive Care Unit will also be involved in
53 the study. These staff will be trained to identify eligible patients and how to notify investigators.
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Informed consent

Trained, GCP-accredited, members of the study team will collect informed consent. The team will discuss the study with the accompanying parent/guardian, or, if both parents are deceased or not actively involved in child care, the main long-term carer of the child will be accepted as the guardian and considered able to give consent for the study. Study staff will describe the purpose of the study, the study procedures, possible risks/benefits, the rights and responsibilities of participants, and alternatives to enrolment. The parent/guardian will be invited to ask questions, which will be addressed by study staff, and they will be provided with appropriate contact numbers if they have any subsequent questions. If the parent/guardian agrees for the child to participate, they will be asked to sign and date an informed consent form. A copy of the patient information sheet and the informed consent form will be given to them to keep. In addition to the procedures above, illiterate signatories will have the Informed Consent Form read to them in the presence of a witness who will sign to confirm this. The parent/guardian can withdraw from the study at any time (verbally) without affecting the care that the child will receive. If the parent/guardian decides at any time to take the child out of the study, no new information will be collected. However, information collected on the child up until that point will still be used. All patient information sheets and consent forms will be written in the local language and will use terms that are easily understandable.

Study procedures

An investigator will routinely record and collect demographic, clinical and laboratory information of the patients, the date of blood draw, the number of blood culture bottles inoculated, the result of the culture (whether positive or negative) and the susceptibility of the isolate to commonly used antimicrobials. Data from these records will be subsequently entered into CliRes Data Management System of Oxford University Clinical Research Unit. These will be source data for this study. The number of patients admitted to the hospital annually will be obtained from hospital records. As part of this study we request that all isolates from blood are stored and archived at -80°C . These isolates will

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3 be re-cultured and the identification will be re-confirmed. Selected isolated organisms from blood will
4 have further molecular characterization at a later date.
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8 **Data collection**

9 ***Demographic and clinical assessments***

10 Data on neonatal sepsis at Children's Hospital 1 will be collected to the case report form. These data
11 will include administrative data, demographic data, clinical characteristics, laboratory results,
12 diagnoses, treatments and outcomes. The Neonatal Therapeutic Intervention Scoring System (NTISS)
13 will be used to estimate the disease severity.(23)
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22 ***Microbiological assessments***

23 Available routine microbiology data on neonatal bloodstream infections Children's Hospital 1. These
24 data will include pathogenic agents isolated from blood culture and antimicrobial susceptibility profile
25 of isolated bacteria (routine panel of antimicrobials). Selected isolates will have additional
26 antimicrobial susceptibility testing, molecular analysis for antimicrobial resistance genes and genome
27 sequencing of selected strains defined by antimicrobial susceptibility data.
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36 **Laboratory methods**

37 ***Microbiology testing***

38 When required for checking or to non-routine antimicrobials, antimicrobial susceptibility testing of
39 the pathogens isolated will be performed by disk diffusion using guidelines established by the Clinical
40 and Laboratory Standards Institute (CLSI) and, when required, by minimum inhibitory concentration
41 estimation (MIC) using the VITEK 2 COMPACT automated machine. Antimicrobial susceptibilities
42 tested will include nalidixic acid, ciprofloxacin, ceftriaxone, cefepime, ampicillin, trimethoprim-
43 sulfamethoxazole, azithromycin, imipenem, colistin and amikacin for all Gram-negative organisms
44 and oxacillin and vancomycin in Gram-positive organisms. The production of extended-spectrum beta
45 lactamases (ESBL) will be investigated using the double-disc synergy test by comparing zone sizes
46 between ceftazidime discs against ceftazidime-clavulanic acid discs and cefotaxime discs against
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3 cefotaxime-clavulanic acid discs. Isolates with an increase in diameter of inhibitory zone of equal to
4 or more than 5 mm by the synergy of clavulanate will be considered ESBL positive.

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6 Organisms including Coryneforms (*Corynebacterium*, etc.), *Micrococci*, *Propionibacterium*, *Bacillus*,
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8 alpha hemolytic *Streptococci*, environmental Gram-negative bacilli, and non-pathogenic *Neisseria*
9
10 will be considered potential contaminants. The pathogen-contaminant decision will be made based on
11
12 the clinical relevance of the isolated bacteria and the independent assessments by two qualified
13
14 medical microbiologists. If there is disagreement then the case will be discussed until a decision is
15
16 reached.
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18 19 20 ***Bacterial storage***

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22 Organisms will be sub-cultured onto 5% blood agar and the purity of the isolate will be tested before
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24 storage in 20% glycerol at -80°C .
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26 27 28 ***Isolation of nucleic acids***

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30 Isolates will be re-cultured and their identification re-checked. DNA will be extracted from bacterial
31
32 isolates using the Wizard Genomic DNA Extraction Kit (Promega, Fitchburg, USA). The quality and
33
34 concentration of the DNA will be assessed using a nano-drop spectrophotometer prior to PCR
35
36 amplification and the Quant-IT Kit (Invitrogen, Carlsbad, CA) prior to DNA sequencing.
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38 39 40 ***PCR for resistance genes***

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42 The primary focus study is to investigate the distribution of antimicrobial resistance genes in bacteria
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44 causing neonatal sepsis. Therefore, all Gram-negative organisms will be investigated by PCR to
45
46 detect genes catalyzing resistance to cephalosporins, fluoroquinolones and carbapenems.

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48 Conventional PCR will be performed for the following classes of resistance genes using previously
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50 described methods. The multiplex and monoplex PCRs are described in these publications. PCR will
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52 be used to detect; AmpC, ESBL (including CTX-M15), NDM, qnr, OXA, KPC and
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54 *mecA/Van*.(11,24–29)
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Genome sequencing

Selected organisms (on the basis of their susceptibility profiles and resistance gene content) will be genome sequenced. We aim to sequence the greatest cross-section of organism groups as possible (i.e. all *Staphylococci* or all *Klebsiella*). Selected bacterial isolates will be sequenced at Oxford University Clinical Research Unit in Vietnam. Briefly, index-tagged paired end Illumina sequencing libraries will be prepared using one of 96 unique indexing tags as previously described. These will be combined into pools of uniquely tagged libraries and sequenced on the Illumina Genome Analyzer or HiSeq sequencer according to manufacturer's protocols to generate tagged 54-100 bp paired-end reads. This is previously approached for describing Gram-negative organisms and *Staphylococcus*.(20,30,31)

Analysis plan

Statistical comparisons

Data will be presented in the form of tables and bar charts for descriptive variables i.e. number of organisms per year and number of AMR organisms per year. Statistical comparisons of features between groups (positive/negative blood culture, Gram negative/Gram positive bacteria, survival/non-survival etc.) and time trend analysis of the cultured isolates by month and the antimicrobial susceptibility patterns will be conducted. These data will be placed in the context of the broader population, by comparison of these data with historical laboratory records of pathogens isolated from patients with bloodstream infections. Historical data from both neonates and older children will be analysed descriptively, and where appropriate, time trend analyses will be performed to determine significant alterations in bloodstream infection aetiology. All statistical analysis will be performed using Stata version 14 (Stata Corp LP, College Station, TX, USA) and R. P-values of ≤ 0.05 will be considered significant.

Antimicrobial resistance genes and genome sequencing

The presence/absence of antimicrobial resistance genes will be reported as proportions per organism and then stratified by organism, year, and hospital department. Genome sequences will be determined

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3 to study phylogenetic relationships, the presence/absence of virulence genes and also AMR gene
4 content and firstly analysed by species and then group by their Gram-stain results. Briefly, for
5 phylogenetic analysis, chromosomal Single Nucleotide Polymorphism (SNP) alleles will be
6 concatenated for each strain to generate a multiple alignment of all SNPs. For maximum likelihood
7 (ML) analysis, RAxML will be run using the generalized time-reversible model and one thousand
8 bootstrap pseudo-replicate analyses were performed to assess support for the ML phylogeny. Root-to-
9 tip branches will be extracted from the ML tree using the program TreeStat. The relationship between
10 root-to-tip distances and year of isolation will be analyzed using linear regression. For BEAST
11 analysis (v1.6), a GTR+ Γ substitution model and defined tip dates, as the date of isolation will be
12 used.(30–32) To detect the presence or absence of genes read sets will be assembled using the *de novo*
13 short read assembler Velvet and Velvet Optimizer. Organism specific read sets will then be aligned to
14 the pan-genome. Taxonomic investigation of accessory and AMR genes will be performed using MG-
15 RAST v3.2.

30 **Ethics, regulatory approvals and governance**

31 This study is sponsored by the University of Oxford and will be monitored by the Clinical Trials Unit
32 at Oxford University Clinical Research Unit (OUCRU). The Principal Investigator (SB) will ensure
33 that this study is conducted in accordance with the principles of the Declaration of Helsinki and the
34 terms of approval of the appropriate ethical committees.(33) The study will be conducted in full
35 conformity with relevant regulations and with the International Council on Harmonization (ICH)
36 Guidelines for Good Clinical Practice (GCP).(34) This protocol and the relevant supporting document
37 have already had the approvals of the Oxford Tropical Research Ethics Committee (OxTREC) and the
38 institutional review board (IRB) of Children's Hospital 1. The investigators will submit and, where
39 necessary, obtain approval from the above parties for all substantial amendments to the original
40 approved documents.

54 **Dissemination and public engagement**

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3 Data from this study will be of interest to the scientific and clinical research communities. An
4 informative resource for managing sepsis will be made available to local clinicians, clinical
5 microbiologists and infection control policy developers. Study data will be reported according to the
6 STROBE guidance for reporting observational studies.⁽³⁵⁾ The authors (and their respective positions
7 in the author list) will be agreed prior to the start of the study in accordance with the guidelines of the
8 International Committee of Medical Journal Editors. In line with Wellcome Trust policy that the
9 results of publicly-funded research should be freely available, manuscripts arising from this study will
10 be submitted to peer-reviewed journals which enable Open Access. In line with research transparency
11 and greater access to data sharing policy of OUCRU in Vietnam will be implemented. This policy is
12 based on a controlled access approach with a restriction on data release that would compromise an on-
13 going trial or study. Data exchange complies with Information Governance and Data Security Policies
14 in all of the relevant countries.

25 26 27 28 **Discussion**

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30 As a conduit for introducing molecular biology for bacteriology into routine hospital care in Vietnam
31 the study is unique, and is planned to lead to future studies investigating appropriate empirical
32 treatment for bacteraemia and the impact of AMR on the outcome of sepsis in the neonatal and
33 paediatric population in Vietnam. By studying and defining disease aetiology, antimicrobial
34 susceptibility patterns and disease outcome we plan to develop an improved approach to managing
35 bloodstream infections in our setting and we will use these data to initiate intervention studies focused
36 on preventing sepsis with AMR pathogens in neonates. Table 2 shows the summary of this study.

37 38 39 40 41 42 43 44 45 **Duration and current status of study**

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47 The first patient was recruited in January 2017. At the current time the recruitment is on-going. The
48 expected end date for recruitment is 31 December 2019. We expect to have completed our data
49 analysis plan with a view of results by June 2020.

50 51 52 53 54 55 **Authors' contributions**

All authors satisfy the criteria for authorship as per the ICMJE 'Recommendations for the Conduct, Reporting, Editing, and Publication of Scholarly Work in Medical Journals'. NDT, TCD, CJB, JIC, AK, EK, LQT, NKM, PTTT, LNTN, NNQM, CNP, NTH, NMX, TCT and SB contributed to the conception and design of the study. NDT, TCD and SB drafted the protocol of the study. This article was drafted by NDT, TCD and SB. CJB, JIC, AK, EK, LQT, NKM, PTTT, LNTN, NNQM, CNP, NTH, NMX, TCT, NDT, TCD and SB read and critically revised the protocol and this article prior to submission.

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Competing interests

All authors have no competing interests to declare.

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Table 1. Clinical and laboratory signs of neonatal sepsis

Clinical signs of sepsis	<ul style="list-style-type: none"> • Abnormal body temperature (core temperature $>38.5^{\circ}\text{C}$ or $<36^{\circ}\text{C}$ and/or temperature instability) • Cardiovascular instability (bradycardia [mean heart rate $<10^{\text{th}}$ percentile for age in the absence of external vagal stimulus, beta-blockers or congenital heart disease or otherwise unexplained persistent depression over a 0.5–4h time period] or tachycardia [mean heart rate $>2\text{SD}$ above normal for age in the absence of external stimulus, chronic unexplained persistent elevation over a 0.5–4h time period] and/or rhythm instability, reduced urinary output ($<1\text{ mL/kg/h}$), hypotension (mean arterial pressure $<5^{\text{th}}$ percentile for age), mottled skin, impaired peripheral perfusion) • Respiratory instability (apnea episodes or tachypnea episodes [mean respiratory rate $>2\text{SD}$ above normal for age] or increased oxygen requirements or requirement for ventilator support) • Gastrointestinal (feeding intolerance, poor sucking, abdominal distension) • Skin and subcutaneous lesions (petechial rash, sclerema) • Non-specific (irritability, lethargy, hypotonia)
Laboratory signs of sepsis	<ul style="list-style-type: none"> • White blood cells $<4 \times 10^9\text{ cells/L}$ or $>20 \times 10^9\text{ cells/L}$ • Immature to total neutrophil ratio (I/T) >0.2 • Platelet count $<100 \times 10^9\text{/L}$ • CRP $>15\text{ mg/L}$ or Procalcitonin $\geq 2\text{ ng/mL}$ • Glucose intolerance (hyperglycemia [blood glucose $>180\text{ mg/dl}$ or 10 mmol/L] or hypoglycemia [blood glucose $<45\text{ mg/dl}$ or 2.5 mmol/L]) • Metabolic acidosis (base excess $<-10\text{ mEq/L}$ or serum lactate $>2\text{ mmol/L}$)

Table 2. Study summary

Title	The clinical features, antimicrobial susceptibility patterns and genomics of bacteria causing neonatal sepsis in a children's hospital in Vietnam
Design	Observational prospective study All organisms isolated from blood will be stored and archived for molecular characterization
Participants	Neonates (≤ 1 month of age) with sepsis
Planned Enrolment Period	2017 – 2019
Primary Objectives	<ul style="list-style-type: none"> • To investigate the clinical characteristics of neonatal sepsis. • To define the aetiology, the percentage of positive blood culture and major causes of sepsis. • To investigate the antimicrobial susceptibilities of the pathogens causing sepsis and the rate of antimicrobial resistance. • To measure the impact of sepsis on the severity of disease and the outcomes (mortality rate, length of stay and cost of treatment) of hospitalized neonates. • To analyse the genome sequences of bacterial strains causing neonatal sepsis.
Secondary Objectives	<ul style="list-style-type: none"> • To analyse the antimicrobial resistance profiles and gene distribution by clinical departments to add insight into the circulation of bacteria causing nosocomial infections. • To study the genes catalysing resistance to the antimicrobials commonly used to treat neonatal sepsis (specifically third/fourth generation cephalosporins, fluoroquinolones and carbapenems).