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Hospitalised Pneumonia Extended (HOPE) Study to reduce the long-term effects of childhood pneumonia: protocol for a multicentre, double-blind parallel, superiority randomised controlled trial

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Manuscripts

HOspitalised Pneumonia Extended (HOPE) Study to reduce the long-term effects of childhood pneumonia: protocol for a multicentre, double-blind parallel, superiority randomised controlled trial

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Abstract

Introduction: Early childhood pneumonia is a common problem globally with long-term complications that include bronchiectasis and chronic obstructive pulmonary disease. It is biologically plausible these long-term effects may be minimised in young children at increased risk of such sequelae if any residual lower airway infection and inflammation in their developing lungs can be treated successfully by longer antibiotic courses. In contrast, shortened antibiotic treatments are being promoted because of concerns over inducing antimicrobial resistance. Nevertheless, the optimal treatment duration remains unknown. Outcomes from randomised controlled trials (RCTs) on paediatric pneumonia have focused on short-term (usually <2-weeks) results. Indeed, no long-term RCT-generated outcome data are available currently. We hypothesise that a longer antibiotic course, compared with the standard treatment course reduces the risk of chronic respiratory symptoms/signs or bronchiectasis 24-months after the original pneumonia episode.

Methods and analysis: This multicentre, parallel, double-blind, placebo-controlled, randomised trial involving seven hospitals in six cities from three different countries commenced in May 2016. Three-hundred-and-fourteen eligible Australian Indigenous, New Zealand Māori/Pacifica and Malaysian children (aged 0.25-5 years) hospitalised for community-acquired, chest x-ray (CXR)-proven pneumonia are being recruited. Following intravenous antibiotics and 3-days of amoxicillin-clavulanate, they are randomised (stratified by site and age groups, allocation-concealed) to receive either: (i) amoxicillin-clavulanate (80mg/kg/day (maximum 980mg of amoxicillin) in two-divided doses or (ii) placebo (equal volume and dosing frequency) for 8-days. Clinical data, nasopharyngeal swab, bloods and CXR are collected. The primary outcome is the proportion of children without chronic respiratory symptom/signs of bronchiectasis at 24-months. The main secondary outcomes are

‘clinical cure’ at 4-weeks, time-to-next respiratory-related hospitalisation and antibiotic resistance of nasopharyngeal respiratory bacteria.

Ethics and dissemination: Ethics committees representing hospitals from all six centres approved the study. The RCT and other results will be submitted for publication.

Trial registration: Australia and New Zealand Clinical Trials Register (ANZCTR) ACTRN12616000046404.

Keywords:

amoxicillin-clavulanate, placebo, pneumonia, randomised controlled trial, children

Strengths and Limitations

- This international, multicentre, parallel, double-blind, placebo-controlled randomised trial will provide important new information on the long-term outcomes of children hospitalised with pneumonia who are closely followed-up within a clinical trial.
- The study will determine whether a longer course of antibiotics (compared with the standard shorter 5-6 day treatment-course) for children hospitalised with pneumonia from disadvantaged communities improves long-term clinical outcomes (reduced symptoms and signs of chronic lung disease), which addresses a large knowledge gap.
- While our inclusion criteria targets those most likely to have bacterial pneumonia, we cannot be certain that some children may have instead pneumonia from a non-bacterial cause.
- Choosing amoxicillin-clavulanate will limit the generalisability of results in settings where amoxicillin is used to treat pneumonia.

For peer review only

Introduction

Acute lower respiratory infections (ALRIs, including pneumonia) are the greatest cause of global childhood morbidity and mortality beyond the neonatal period.^{1,2} Moreover, they are associated with future deficits in pulmonary function³ and chronic lung disease, including bronchiectasis⁴ and chronic obstructive pulmonary disease (COPD).⁵ Bronchiectasis and non-smoking related COPD⁵ are both highly prevalent in disadvantaged 'at risk populations' encountered in low-to-middle income countries⁶ and amongst Indigenous peoples.^{7,8} Our earlier case-control study among Indigenous children in Central Australia found that a history of hospitalised pneumonia significantly increased the risk of having bronchiectasis (odds ratio (OR) 15.2, 95% confidence interval (CI) 4.4-52.7).⁴ Furthermore, both COPD and bronchiectasis are associated with early mortality where for example bronchiectasis causes premature death in the 3rd–4th decade of life in Australian Indigenous adults⁹. Yet, many knowledge gaps in managing pneumonia remain, especially the optimal duration of antibiotic treatment,¹⁰ while the full extent of the medium and long-term consequences of pneumonia are largely unknown.^{2,11,12}

As the World Health Organization (WHO) diagnostic algorithm for pneumonia used in resource-poor settings is designed to reduce mortality, it sacrifices specificity for sensitivity. Antibiotics are given to all those suspected of clinical pneumonia. In non-HIV infected children aged <5-years, 3-days of oral amoxicillin is recommended for all those with tachypnoea alone and is extended to 5-days if subcostal recession is also present. Those with severe clinical pneumonia (e.g. dehydration, altered conscious state) receive 5-days of intravenous antibiotics (penicillin/ampicillin and gentamicin).¹ These recommendations are based on several large randomised controlled trials (RCTs) of oral versus intravenous antibiotics and 3 vs 5-days of oral antibiotics conducted in children living in low-income

countries.^{13,14} The adjusted failure rate on day-6 in the four largest studies was 8.5% (95%CI 5.9-11.5%).¹³ However, the external validity of these studies is limited and biased towards equivalence where neither treatment will be effective as most subjects diagnosed with clinical pneumonia likely had bronchiolitis or viral ALRIs because: (1) over half the subjects were infants, (2) 20-80% had wheeze, (3) chest x-rays (CXR) were either not performed or abnormal in <20% of cases, and (4) oral amoxicillin and placebo produced equivalent outcomes in infants aged 2-59 months.¹⁵ In this context, the shorter courses of antibiotics recommended by WHO cannot be extrapolated to pneumonia that is likely to be caused by bacterial pathogens¹⁶ in children at high-risk of on-going morbidity, the target group of our study.

In comparison, in CXR-confirmed hospitalised pneumonia, there is little information guiding treatment duration. A single-centre 3-arm RCT involving 140 non-hospitalised children aged <5-years from Israel with likely bacterial pneumonia (based on clinical criteria, CXR, white blood cell counts) found that the failure rate of a 3-day course of amoxicillin (80mg/kg/day in three divided doses) in this patient group (40%) was unacceptably high.¹⁷ In contrast, 5 and 10-days of oral amoxicillin using the same dosing regimen had equivalent outcomes (no failures).¹⁷ Consequently, the duration of antibiotic treatment recommended in national guidelines for pneumonia varies between low-income (WHO 3-5 days) and high-income countries (5-10 days).^{17,18} The few RCTs of antibiotic duration for treating child pneumonia report only short-term outcomes (eg. mortality, persistent fever and respiratory signs after 5-days, or relapse within 1-2 weeks with only one study following subjects for 30-days).^{14,17,18} None have examined the duration of chronic symptoms (e.g. wet cough >4-weeks) post-treatment, subsequent respiratory-associated hospitalisations or persistent CXR abnormalities following pneumonia. These outcomes beyond the 4-week time point are

important as we¹⁹ and others²⁰ have shown that chronic wet cough in children implies lower airway infection and intense inflammation, as seen in protracted bacterial bronchitis.

Longer antibiotic courses may be beneficial in selected settings. Although controversial, in adults with ventilator-associated pneumonia, a meta-analysis found evidence for increased risk of relapse with shorter antibiotic treatments (OR 1.7; 95%CI 1.0, 2.8) during the following 4-weeks and all clinical point-estimates favoured longer treatment courses.²¹ Supportive meta-analysis and large RCT data in other bacterial infections (streptococcal tonsillitis,²² otitis media in children aged <2-years^{23,24} and urinary tract infections²⁵) show higher recurrence, failure and/or poorer bacterial eradication rates with shorter (<7-days) antibiotic courses. Thus, preventing persistent wet cough (indicating presence of infected secretions) and/or recurrent ALRIs or pneumonia after an initial episode of pneumonia could have long-term benefits for lung health in children from groups deemed to be at high-risk of these complications.²⁶

Young 'at-risk' children, such as disadvantaged Indigenous children⁴ and those in low-income countries, are heavily colonised with respiratory bacterial pathogens from an early age and may benefit from a longer antibiotics course for severe pneumonia to increase the likelihood of pathogen clearance from their airways and to reduce the risk of persistent inflammation and airway injury. These young children have developing lungs (hence more susceptible to injury)²⁷ and the presence of protracted low grade infection and inflammation post-ALRI could trigger the vicious cycle associated with bronchiectasis.^{27,28} Thus, a longer antibiotic course for young children hospitalised with severe pneumonia could enhance bacterial clearance and reduce the risk of long-term complications.

We are therefore undertaking a RCT comparing ‘longer’ with standard (‘shorter’) antibiotic treatment courses for severe pneumonia. We are aware that longer antibiotic treatment for all children might increase antibiotic resistance and lead to ‘over-treatment’ of some children. Thus, we are also monitoring antibiotic resistance in respiratory bacterial pathogens from the nasopharynx.

Study objectives and hypotheses

Our primary question is: Does a longer (13-14 days) course of antibiotics, compared to a shorter (5-6 days) one, improve the long-term clinical outcome of children hospitalised with severe community-acquired, CXR-confirmed pneumonia? Our primary hypothesis is that a longer antibiotic course, compared with the standard treatment course reduces the risk of chronic respiratory symptoms/signs or bronchiectasis at 24-months after the original episode of pneumonia.

Our secondary aims are to:

1. Determine the effects of antibiotic course duration upon (i) clinical cure rates (at 4-weeks), (ii) time-to-next hospitalisation for a respiratory illness and (iii) antibiotic resistance in respiratory pathogens isolated from the nasopharynx.
2. Identify the predictors of chronic respiratory symptoms or bronchiectasis, specifically the contribution of persistent CXR abnormalities 4-weeks following treatment for pneumonia.

Our secondary hypotheses are that: (1) a longer antibiotic course with amoxicillin-clavulanate compared with the standard treatment course (a) improves clinical cure rates at 4-weeks, (b) lengthens the time-to-next exacerbation, and (c) does not increase antibiotic resistance in

nasopharyngeal respiratory bacterial pathogens; and (2) children who develop chronic respiratory symptoms can be identified earlier by the persistence of CXR abnormalities 4-weeks after an episode of pneumonia.

Methods and Analysis

Study setting and design

We are conducting a multicentre, parallel group, double-blind placebo, RCT (with concealed allocation) involving the paediatric departments of seven participating hospitals in six cities from three different countries: Royal Darwin Hospital in Darwin, Northern Territory (NT, Australia); Starship Children's Hospital and KidzFirst Hospital in Auckland (New Zealand); and four Malaysian cities (Likas Hospital in Kota Kinabalu, Sabah; Sarawak General Hospital in Kuching, Sarawak; University of Malaya Medical Centre in Kuala Lumpur, Wilayah Persekutuan; and Hospital Tengku Ampuan Rahimah in Klang, Selangor). Our study design, summarised in Figure 1, is in accordance with the recommendations for Interventional Trial (SPIRIT) guidelines.²⁹ Our study is on-going; we recruited our first participant on May 30th, 2016 (in Darwin) and expect to continue recruiting until late 2019 with the study anticipated to be completed by late 2021.

Study population

The inclusion criteria are:

- 1) Hospitalised children aged 3-months to <5-years (restricted to Aboriginal and Torres Strait Islander children in Darwin; and Māori or Pacifica (Pacific Islander) children in Auckland);
- 2) Features of severe pneumonia on admission (fever $\geq 37.5^{\circ}\text{C}$, age-adjusted tachypnoea [respiratory rate (RR) ≥ 50 if aged ≤ 12 -months; RR ≥ 40 if > 12 -months] with chest wall

- recession and/or SpO₂ <92% in air)³⁰ and consolidation on CXR as evaluated by the treating clinician;³¹
- 3) Becoming afebrile within 1-3 days of commencing intravenous antibiotics, with improved respiratory symptoms and signs, SpO₂ ≥92% in air and are ready to be switched to oral amoxicillin-clavulanate; and
- 4) Had symptoms for ≤7-days at the time of admission to hospital.

Exclusion criteria are: (1) current wheeze (during hospitalisation); (2) underlying co-morbidities other than asthma (e.g. bronchiectasis, cyanotic congenital heart disease, cardiac failure, neuromuscular disorders, immunodeficiency) that could potentially influence the current illness; (3) severe malnutrition (weight-for-height Z-score <-3.0); (4) complicated pneumonia (effusion, empyaema or abscess, tuberculosis) and/or where pathogens are identified that require different antibiotics or extended courses of treatment (eg. *Staphylococcus aureus*, *Burkholderia pseudomallei*, *Mycobacterium tuberculosis* or *Mycoplasma pneumoniae*); (5) concurrent extra-pulmonary infection requiring additional antibiotic therapy (e.g. meningitis); (6) penicillin allergy; (7) enrolled in the study previously; or (8) unable to return for follow-up clinic visits during the next 24-months.

Recruitment

Eligible children with radiographic-confirmed pneumonia are identified by a member of the research team visiting the paediatric wards of each hospital twice-daily. Within 24-hours of admission to the paediatric ward, the parent/guardian of a potentially eligible child is approached. A member of the research team discusses the study with the parent/guardian in detail using the consent flipchart, information booklet and interpreters (where appropriate). After all aspects of study are explained, including potential risks

and benefits, written informed consent is obtained from the parent/guardian in those who agree to participate in the study. Each site maintains a screening log with limited details recorded [screening number, date, age and sex of the person, whether informed consent was obtained or reason for refusal (if the participant wishes to provide that information)].

During hospitalisation, children with uncomplicated segmental or lobar pneumonia receive 1-3 days of intravenous site-specific antibiotics (either ampicillin or benzylpenicillin G according to the hospital's protocol) and oxygen supplementation if SpO₂ in air $\leq$ 92%. Other clinical management (e.g. intravenous fluids, antipyretics, nutritional support) is at the discretion of the treating paediatrician. The eligibility of children who have been consented is reassessed when they are ready to "step down" from intravenous to oral antibiotics. In children not eligible for randomisation (i.e. not meeting the full eligibility criteria), the parent/guardian is advised that their child will be managed in accordance with the treating hospital team's routine pneumonia protocol. Those meeting the inclusion criteria are then enrolled into the RCT and randomised to one of the two treatment arms that follow on from the 3-days of oral amoxicillin-clavulanate received by all trial participants.

Randomisation and allocation

The randomisation sequence was computer-generated and used random permuted block sizes of 4 to 8, prepared by a statistician external to the study team. Treatment groups are allocated according to the randomisation code. Upon enrolment, the child is assigned to the next unique number on the appropriate stratified list. The allocation is performed by the trial pharmacist at the respective hospitals. Randomisation is stratified by city site (Darwin, Auckland, Kota Kinabalu, Kuching, Kuala Lumpur, Klang) and age (<1 or 1-5 years). The

allocation sequence is concealed throughout the study until data analyses are complete.

Treatment groups and blinding

After ceasing intravenous antibiotics and completing the 3-days of oral amoxicillin-clavulanate 400/57 duo suspension formulation (80mg/kg/day of the amoxicillin component in two divided doses), the children randomised to one of two treatment groups will receive either (1) in the active arm: 8-days of oral amoxicillin-clavulanate 400/57 duo suspension (80mg/kg/day of amoxicillin component in two divided doses; max 980 mg per day); or (2) in the control arm: 8-days of oral placebo suspension (in two divided doses in volumes equal to the active arm). The placebo medication, manufactured specifically by the Institute of Drug Technology Australia Limited (Melbourne, Victoria), has an indistinguishable taste, smell, texture and appearance to the active medication, as used previously.³² Both the active antibiotic and placebo are in matched opaque bottles. For all trial medications, equal volumes of water are added using a syringe in a child-safety, sealed, opaque bottle. Thus, blinding of the child’s allocation group will be maintained throughout the trial until the analyses is complete. Unblinding will be only be permissible if a serious adverse event occurs and we are requested by the independent data monitoring committee (iDMC) to unblind the child’s allocated group.

Data collection

Data are collected from the parent/guardian and from the medical records at baseline (enrolment), 4-weeks, 12- and 24-months post-hospital discharge. On enrolment, demographic information (age, sex, ethnicity, household size, etc), birth history, breast-feeding history, prior illness, immunisation record, in-utero and household smoke exposure are recorded, and a physical examination performed by trained research staff. Immunisation

data are collected from the respective country's immunisation register or patients' records. All data are documented on hard copy standardised forms and entered into the database at a later date. Electronic forms are not used because of the instability of the internet connection at some sites.

As with our previous RCTs,^{33,34} children are prospectively followed after being discharged from hospital. In the current study, follow-up is for 24-months post-hospital discharge with clinical reviews at the hospital or local health clinics at 4-weeks, 12- and 24-months. The primary and secondary outcome measures are collected at the time points below. Serious and non-serious (nausea, vomiting, diarrhoea, rash) adverse-events are documented and monitored. Safety exit points are discussed below. Adherence is assessed by parent report and return of empty bottles.

Specimen collection

At enrolment (baseline) as close as possible to the day of admission, and again at 4-weeks and 12-months following hospital admission for pneumonia, all children will have nasopharyngeal swabs taken, which are placed immediately into skim milk tryptone glucose glycerol broth medium and kept cold until stored at -80°C.

Routine blood collection (i.e. full blood count and blood cultures) are undertaken by the treating hospital medical team upon admission and these data are recorded. Also, CXRs are performed at admission (in all cases) and at 4-weeks and 12-months when possible (i.e. some children living in remote regions are unable to travel to the treating hospital for a CXR).

Treatment failure and exit criteria during the study

Monitoring of adverse and serious adverse events are undertaken throughout the trial using standardised adverse and serious adverse event forms. Treatment failure and exit criteria are defined as occurrence within 4-weeks of enrolment of any of the following: (1) death, (2) secondary fever ($>38^{\circ}\text{C}$) with new signs of clinical pneumonia or (3) new CXR changes. Participants are discontinued from the study protocol if the parent/guardian withdraws consent for participation, the child or parent/guardian are unable to comply with study procedures or if a trial medication-related serious adverse event or exit criterion occurs.

Outcome measures

Our primary outcome is the proportion of children without chronic respiratory symptoms/signs or bronchiectasis³⁵ at 24-months following hospitalisation for pneumonia. Our secondary outcomes are: (1) the proportion with clinical cure (i.e. complete resolution of respiratory symptoms and signs) at 4-weeks; (2) time-to-next respiratory-related hospitalisation; (3) CXR abnormalities and; (4) adverse events. Our secondary laboratory outcomes are nasopharyngeal respiratory bacterial pathogens and antibiotic resistance (4-weeks, 12-months).

Similar to our other intervention RCTs,^{32-34,36} medical record review at community health centres and each of the hospital sites will identify respiratory rehospitalisation episodes and prior investigations for chronic lung diseases, including radiographic investigations for bronchiectasis. Additionally, parents will be specifically asked about rehospitalisations and whether a chest CT scan has been undertaken.

CXRs are digitised and anonymised. These will be scored independently by two people (respiratory physicians or radiologist) in a blinded manner. CXR abnormalities on follow-up will be dichotomised into abnormal (presence of new or persistent parenchymal densities or infiltrates)^{31,37} or normal. Disagreements will be resolved by consensus.

The stored nasopharyngeal swabs will be processed as done previously.^{32,36} Briefly, batches of swabs will be thawed and cultured on selective media. *Streptococcus pneumoniae*, *Haemophilus influenzae*, *Moraxella catarrhalis* and *S. aureus* will be confirmed by standard techniques.^{36,38} Based upon their colonial morphology, four isolates each of *S. pneumoniae*, *H. influenzae*³⁸ and *S. aureus* will have their antibiotic susceptibilities determined by the calibrated susceptibility disc diffusion method.³⁶ The minimum inhibitory concentration for penicillin for *S. pneumoniae* will be determined by E-tests if the oxacillin disc zone is <6mm; and for *H. influenzae* if the ampicillin disc zone is <6mm.³⁶ The European Committee on Antimicrobial Susceptibility Testing criteria will identify resistant isolates. A nitrocephin-based test will detect beta-lactamase activity in *H. influenzae* and *M. catarrhalis* isolates.

Sample size

Sample size estimates are based on our primary outcome (proportion without chronic respiratory symptoms/signs or bronchiectasis). We wish to detect a significant difference between the active arm (i.e. longer antibiotic course) and the control arm (i.e. shorter antibiotic course). We assume the percentage without chronic respiratory morbidity (at 24-months) in the short antibiotic group (controls) is 65.9% (based on our previous Central Australian pneumonia study³¹ where 34.1% had persistent respiratory morbidity at 12-months). To find a 50% reduction in bronchiectasis (or chronic respiratory symptoms), the percentage without bronchiectasis in the long antibiotic group will be 82.9%. For 89% power

and $\alpha=0.05$, we require outcome data from 131 patients in each treatment group. Adding 20% (for participant drop-out), we will enrol 157 children in each group. To mitigate the possibility of an even higher drop-out rate, we will replace participants that missed the 12-month follow-up, until late 2019. Replacements will be assigned a new identification number and treatment.

Statistical analyses and reporting

Data coding and entry is based at Darwin and conducted in accordance with good clinical practice. Data will be reported and presented in accordance with the updated CONSORT criteria.³⁹ Children will be analysed according to the intention-to-treat principle where analysis will be by allocation status regardless of subsequent management. A detailed statistical analysis plan that is approved by the iDMC will be in place prior to data analyses.

For our primary aim, the main effects of the intervention will be determined by comparing the proportion without any chronic respiratory symptoms/signs or evidence of bronchiectasis at 24-months. We will report relative risk calculated via log-binomial regression models. Linear regression will be used to calculate absolute differences between proportions (with 95%CI), as in previous analyses.^{32,36}

For our secondary aims, the effects of the interventions will be determined by (1) comparing the proportion with clinical cure (complete resolution of respiratory symptoms and signs) at 4-weeks and; (2) constructing a Kaplan-Meier curve for each group for time-to-next respiratory-related hospitalisation, and proportions will be compared using the log-rank test as well as time-to-event regression models (as above). Logistic regression will be used to examine the effects of treatment duration upon respiratory bacterial pathogen colonisation in

the nasopharynx and antibiotic resistance with models adjusted for potentially confounding demographic, social and clinical variables as appropriate, as done previously.^{32,36} CXR abnormality data will be compared between children with and without chronic respiratory symptoms/bronchiectasis. CXR abnormalities will be dichotomised (present/absent) and χ^2 tests used to determine the OR with 95% CIs for presence of chronic symptoms/bronchiectasis.

Patient and public involvement

The study was discussed with, and approved by, the Indigenous Reference Group (Darwin) prior to submitting the grant applications and beginning the study. Also, the study was discussed with, and approved by, the Māori Research Review Committee (Auckland) prior to submitting the New Zealand-based grant application and commencement of the study in New Zealand in 2017. Patients were not involved in the study question or design but the above committees have grandchildren who have children with pneumonia who approved of the study design and outcome measures.

Ethics, dissemination and safety monitoring

The Human Research Ethics Committees of all the recruiting institutions (Darwin: Northern Territory Department of Health and Menzies School of Health Research; Auckland: Starship Children's and KidsFirst Hospitals; East Malaysia: Likas Hospital and Sarawak General Hospital; Kuala Lumpur: University of Malaya Research Ethics Committee; and Klang: Malaysian Department of Health) have approved the research protocol.

We will publish the results in a major medical journal, and share the outcomes with the academic and medical community, funding and relevant patient organisations. All adverse

events, including serious adverse events, are monitored by an iDMC, which was established and met prior to commencing the study. An Indigenous Reference Group oversees the cultural aspects of the study.

Discussion

We are currently undertaking a multicentre, double-blind RCT in three countries to address the question of whether a longer course of antibiotics (13-14 days), compared to the standard short course (5-6 days), for treating young children hospitalised with community-acquired pneumonia (assumed to be of bacterial origin) reduces its long-term complications. The biological plausibility of our hypothesis was presented above. The outcomes and time points were chosen carefully as described below.

Rationale for our chosen outcome measures and time frame

Chronic cough (defined as >4-weeks duration^{40,41}) can occur post-ALRIs.⁴² In children, chronic cough has an often unrecognised high morbidity,⁴³ may reflect the underlying cause,⁴⁴ and is the dominant symptom of bronchiectasis.²⁷ In a national study, we found that 9% of 346 children newly-referred for chronic cough had bronchiectasis, which was significantly more likely in Indigenous than non-Indigenous children (OR 4.4, 95%CI 1.9, 10.0).⁴⁴ Further, our follow-up study of young children hospitalised for bronchiolitis identified that the persistence of cough at 3-4 weeks post-discharge significantly increased the OR of having bronchiectasis detected at a median of 13-months post-index hospitalisation.⁴⁵ Also, our earlier study observed that of 109 Indigenous NT children hospitalised with CXR-proven pneumonia, of whom 90 (83%) were reviewed at 12-months, 23/90 (26%) had a new treatable chronic respiratory illness.³¹ Finally in a New Zealand study,⁴⁶ 94/164 (74%) (86% Māori/Pacifica) infants and young children hospitalised before

age 2-years for bronchiolitis (44%) or pneumonia (56%) underwent a clinical review 12-months later where 81 also had a repeat CXR. Overall, in the follow-up cohort 29/94 (31%) had a chronic wet cough history, 30 (32%) still had a cough with or without chest crackles on examination and 50/81 (62%) had pulmonary infiltrates present.⁴⁶ Thus, we chose these outcomes (chronic cough, CXR changes) evaluated at 4-weeks, 12- and 24-months post-hospitalisation for pneumonia as they are important markers for future lung health.

Rationale for amoxicillin-clavulanate

Amoxicillin is the recommended oral antibiotic for treating non-severe pneumonia in young children aged <5-years from both high and low-to-middle income countries.^{1,30} Our original intention was to use amoxicillin as 'step-down' therapy in the RCT, but unfortunately the cost of preparing and manufacturing its placebo proved prohibitive. Instead, we chose amoxicillin-clavulanate, since from our previous studies it was well tolerated and importantly we had both access and guaranteed supply of a validated placebo medication, indistinguishable from the active antibiotic.^{32,47} Because of its broader-spectrum of action, amoxicillin-clavulanate is recommended as a second-line agent for inpatient and outpatient treatment of pneumonia.^{1,30} Nevertheless, a recent survey of 19 hospitals in 16 European countries identified it was used as a first-line antibiotic by more than 25% of centres for treating paediatric community-acquired pneumonia in both hospital and community settings.⁴⁸ Amoxicillin-clavulanate offers the theoretical advantage of activity against β -lactamase producing strains of *H. influenzae* and *M. catarrhalis* that heavily colonise the upper airways of these young children and may play a role in establishing chronic lung disease following an episode of severe pneumonia.^{4,12} The accompanying risk of course is causing airway dysbiosis with enrichment by antibiotic-resistant organisms. To this end we are monitoring antibiotic susceptibility patterns of nasopharyngeal respiratory bacterial

pathogens 4-weeks and 12-months after commencing treatment for pneumonia. The nasopharynx was chosen because of its relative ease of sampling access and as it acts as reservoir for transmitting antibiotic-resistant respiratory bacterial pathogens within the community.⁴⁹

In summary, our study addresses a large knowledge gap of a common worldwide problem in early childhood pneumonia. The multicentre nature of our study increases the generalisability of the future findings of our RCT that is complemented by assessing predictors of future morbidity.

Authors' contributions

AC conceived and designed the study, drafted the manuscript and was primarily responsible for obtaining the grant. KG co-conceived and designed the study, had a major input into the grant submission and edited the manuscript. RW led the statistical components for grant submission. JU, SF, TY, MO, AN, JdB, PM, BL, PT contributed to study design, grant submission and manuscript. CB is the lead investigator at the Auckland site and obtained a 2-year grant for recruiting the children in New Zealand. SF is the lead investigator in Kota Kinabalu, MO is the lead investigator in Kuching, AN is the lead investigator in Kuala Lumpur and obtained a Malaysian grant that supported the study in Kuala Lumpur. NN and NS are the lead investigators at the Klang site. GM initiated the project, prepared the SOPs, submitted the ethics application and is currently coordinating all aspects of the project. HSV leads the laboratory component of assessing nasopharyngeal bacteria and its resistance to antibiotics. All authors read and approved the final manuscript.

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Figure legend

Overall schematic study design.

Abbreviations: ABs, antibiotics; CXR, chest x-ray; NPS, nasopharyngeal swab.

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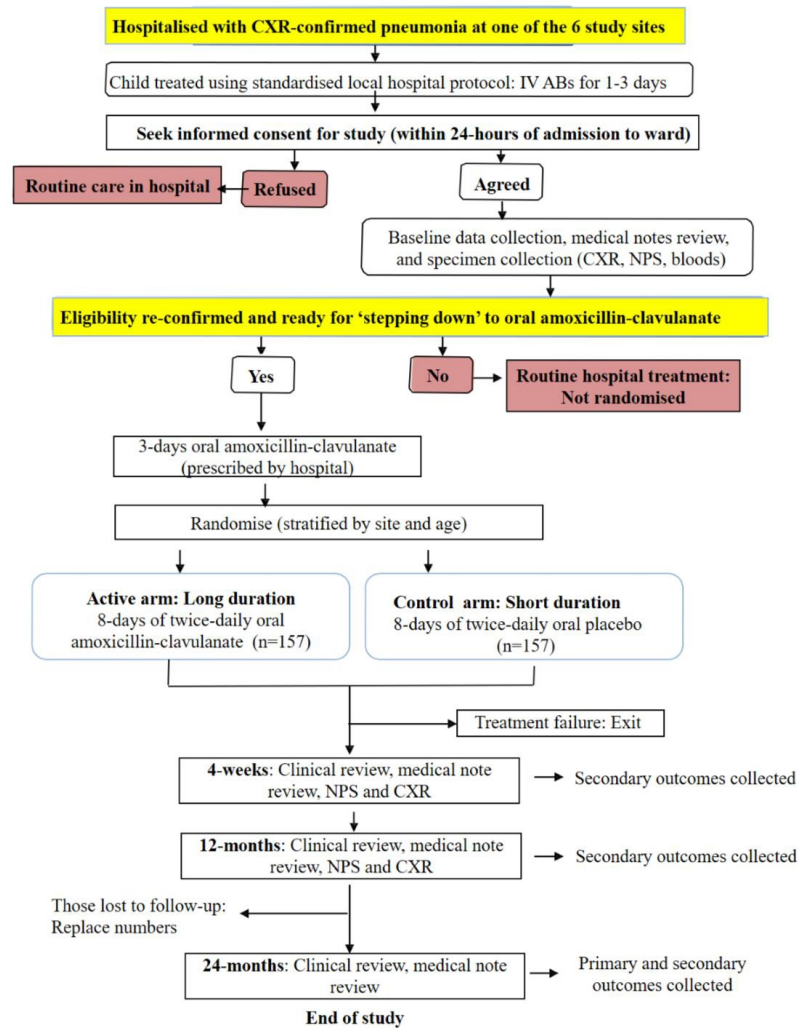


Figure 1

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Hospitalised Pneumonia Extended (HOPE) Study to reduce the long-term effects of childhood pneumonia: protocol for a multicentre, double-blind parallel, superiority randomised controlled trial

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Manuscripts

Hospitalised Pneumonia Extended (HOPE) Study to reduce the long-term effects of childhood pneumonia: protocol for a multicentre, double-blind parallel, superiority randomised controlled trial

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Abstract

Introduction: Early childhood pneumonia is a common problem globally with long-term complications that include bronchiectasis and chronic obstructive pulmonary disease. It is biologically plausible these long-term effects may be minimised in young children at increased risk of such sequelae if any residual lower airway infection and inflammation in their developing lungs can be treated successfully by longer antibiotic courses. In contrast, shortened antibiotic treatments are being promoted because of concerns over inducing antimicrobial resistance. Nevertheless, the optimal treatment duration remains unknown. Outcomes from randomised controlled trials (RCTs) on paediatric pneumonia have focused on short-term (usually <2-weeks) results. Indeed, no long-term RCT-generated outcome data are available currently. We hypothesise that a longer antibiotic course, compared with the standard treatment course, reduces the risk of chronic respiratory symptoms/signs or bronchiectasis 24-months after the original pneumonia episode.

Methods and analysis: This multicentre, parallel, double-blind, placebo-controlled, randomised trial involving seven hospitals in six cities from three different countries commenced in May 2016. Three-hundred-and-fourteen eligible Australian Indigenous, New Zealand Māori/Pacific, and Malaysian children (aged 0.25-5 years) hospitalised for community-acquired, chest x-ray (CXR)-proven pneumonia are being recruited. Following intravenous antibiotics and 3-days of amoxicillin-clavulanate, they are randomised (stratified by site and age group, allocation-concealed) to receive either: (i) amoxicillin-clavulanate (80mg/kg/day (maximum 980mg of amoxicillin) in two-divided doses or (ii) placebo (equal volume and dosing frequency) for 8-days. Clinical data, nasopharyngeal swab, bloods and CXR are collected. The primary outcome is the proportion of children without chronic respiratory symptom/signs of bronchiectasis at 24-months. The main secondary outcomes are ‘clinical

cure' at 4-weeks, time-to-next respiratory-related hospitalisation and antibiotic resistance of nasopharyngeal respiratory bacteria.

Ethics and dissemination: Ethics committees representing hospitals from all six centres approved the study. The RCT and other results will be submitted for publication.

Trial registration: Australia and New Zealand Clinical Trials Register (ANZCTR) ACTRN12616000046404.

Keywords:

amoxicillin-clavulanate, placebo, pneumonia, randomised controlled trial, children

Strengths and Limitations

- This international, multicentre, parallel, double-blind, placebo-controlled randomised trial will provide important new information on the long-term outcomes of children hospitalised with pneumonia who are closely followed-up within a clinical trial.
- The study will determine whether a longer course of antibiotics (compared with the standard shorter 5-6 day treatment-course) for children hospitalised with pneumonia from disadvantaged communities improves long-term clinical outcomes (reduced symptoms and signs of chronic lung disease), which addresses a large knowledge gap.
- While our inclusion criteria targets those most likely to have bacterial pneumonia, we cannot be absolutely certain that some children do not have pneumonia solely from a non-bacterial cause.
- Choosing amoxicillin-clavulanate may limit the generalisability of results in settings where amoxicillin is generally used to treat pneumonia.

Introduction

Acute lower respiratory infections (ALRIs, including pneumonia) are the greatest cause of global childhood morbidity and mortality beyond the neonatal period.^{1,2} Moreover, they are associated with future deficits in pulmonary function³ and chronic lung disease, including bronchiectasis⁴ and chronic obstructive pulmonary disease (COPD).⁵ Bronchiectasis and non-smoking related COPD⁵ are both highly prevalent in disadvantaged ‘at risk populations’ encountered in low-to-middle income countries⁶ and amongst Indigenous peoples.^{7,8} Our earlier case-control study among Indigenous children in Central Australia found that a history of hospitalised pneumonia significantly increased the risk of having bronchiectasis (odds ratio (OR) 15.2, 95% confidence interval (CI) 4.4-52.7).⁴ Furthermore, both COPD and bronchiectasis are associated with early mortality where, for example, bronchiectasis causes premature death in the 3rd–4th decade of life in Australian Indigenous adults⁹. Yet, many knowledge gaps in managing pneumonia remain, especially the optimal duration of antibiotic treatment,¹⁰ while the full extent of the medium and long-term consequences of pneumonia are largely unknown.^{2,11,12}

As the World Health Organization (WHO) diagnostic algorithm for pneumonia used in resource-poor settings is designed to reduce mortality, it sacrifices specificity for sensitivity. Antibiotics are recommended for all those suspected of clinical pneumonia. In non-HIV infected children aged <5-years, 3-days of oral amoxicillin is recommended for all those with tachypnoea alone and is extended to 5-days if subcostal recession is also present. Those with severe clinical pneumonia (e.g. dehydration, altered conscious state) receive 5-days of intravenous antibiotics (penicillin/ampicillin and gentamicin).¹ These recommendations are based on several large randomised controlled trials (RCTs) of oral versus intravenous antibiotics and 3 vs 5-days of oral antibiotics conducted in children living in low-income

countries.^{13,14} The adjusted failure rate on day-6 in the four largest studies was 8.5% (95%CI 5.9-11.5%).¹³ However, the external validity of these studies is limited and biased towards equivalence where neither treatment will be effective as most subjects diagnosed with clinical pneumonia likely had bronchiolitis or viral ALRIs because: (1) over half the subjects were infants, (2) 20-80% had wheeze, (3) chest x-rays (CXR) were either not performed or abnormal in <20% of cases, and (4) oral amoxicillin and placebo produced equivalent outcomes in infants aged 2-59 months.¹⁵ In this context, the shorter courses of antibiotics recommended by WHO cannot be extrapolated to pneumonia that is likely to be caused by bacterial pathogens¹⁶ in children at high-risk of on-going morbidity, the target group of our study.

In comparison, in CXR-confirmed hospitalised pneumonia, there is little information guiding treatment duration. A single-centre 3-arm RCT involving 140 non-hospitalised children aged <5-years from Israel with likely bacterial pneumonia (based on clinical criteria, CXR, white blood cell counts) found that the failure rate of a 3-day course of amoxicillin (80mg/kg/day in three divided doses) in this patient group (40%) was unacceptably high.¹⁷ In contrast, 5 and 10-days of oral amoxicillin using the same dosing regimen had equivalent outcomes (no failures).¹⁷ Consequently, the duration of antibiotic treatment recommended in national guidelines for pneumonia varies between low-income (WHO 3-5 days) and high-income countries (5-10 days).^{17,18} The few RCTs of antibiotic duration for treating child pneumonia report only short-term outcomes (eg. mortality, persistent fever and respiratory signs after 5-days, or relapse within 1-2 weeks with only one study following subjects for 30-days).^{14,17,18} No studies have examined the duration of chronic symptoms (e.g. wet cough >4-weeks) post-treatment, subsequent respiratory-associated hospitalisations or persistent CXR abnormalities following pneumonia. These outcomes beyond the 4-week time point are important as we¹⁹

and others²⁰ have shown that chronic wet cough in children implies lower airway infection and intense inflammation, as seen in protracted bacterial bronchitis.

Longer antibiotic courses may be beneficial in selected settings. Although controversial, in adults with ventilator-associated pneumonia, a meta-analysis found evidence for increased risk of relapse with shorter antibiotic treatments (OR 1.7; 95%CI 1.0, 2.8) during the following 4-weeks and all clinical point-estimates favoured longer treatment courses.²¹ Supportive meta-analysis and large RCT data in other bacterial infections (streptococcal tonsillitis,²² otitis media in children aged <2-years^{23,24} and urinary tract infections²⁵) show higher recurrence, failure and/or poorer bacterial eradication rates with shorter (<7-days) antibiotic courses. Thus, preventing persistent wet cough (indicating presence of infected secretions) and/or recurrent ALRIs or pneumonia after an initial episode of pneumonia could have long-term benefits for lung health in children from groups deemed to be at high-risk of these complications.²⁶

Young ‘at-risk’ children, such as disadvantaged Indigenous children⁴ and those in low-income countries, are heavily colonised with respiratory bacterial pathogens from an early age and may benefit from a longer antibiotics course for severe pneumonia to increase the likelihood of pathogen clearance from their airways and to reduce the risk of persistent inflammation and airway injury. These young children have developing lungs (hence more susceptible to injury)²⁷ and the presence of protracted low grade infection and inflammation post-ALRI could trigger the vicious cycle associated with bronchiectasis.^{27,28} Thus, a longer antibiotic course for young children hospitalised with severe pneumonia could enhance bacterial clearance and reduce the risk of long-term complications.

We are therefore undertaking a RCT comparing 'longer' with standard ('shorter') antibiotic treatment courses for severe pneumonia. We are aware that longer antibiotic treatment for all children might increase antibiotic resistance and lead to 'over-treatment' of some children. Thus, we are also monitoring antibiotic resistance in respiratory bacterial pathogens from the nasopharynx.

Study objectives and hypotheses

Our primary question is: Does a longer (13-14 days) course of antibiotics, compared to a shorter (5-6 days) one, improve the long-term clinical outcome of children hospitalised with severe community-acquired, CXR-confirmed pneumonia? Our primary hypothesis is that a longer antibiotic course, compared with the standard treatment course reduces the risk of chronic respiratory symptoms/signs or bronchiectasis at 24-months after the original episode of pneumonia.

Our secondary aims are to:

1. Determine the effects of antibiotic course duration upon: (i) clinical cure rates (at 4-weeks), (ii) time-to-next hospitalisation for a respiratory illness and (iii) antibiotic resistance in respiratory pathogens isolated from the nasopharynx.
2. Identify the predictors of chronic respiratory symptoms or bronchiectasis, specifically the contribution of persistent CXR abnormalities 4-weeks following treatment for pneumonia.

Our secondary hypotheses are that: (1) a longer antibiotic course with amoxicillin-clavulanate compared with the standard treatment course (a) improves clinical cure rates at 4-weeks, (b) lengthens the time-to-next exacerbation, and (c) does not increase antibiotic resistance in nasopharyngeal respiratory bacterial pathogens; and (2) children who develop chronic

recession and/or $\text{SpO}_2 < 92\%$ in air)³⁰ and consolidation on CXR as evaluated by the treating clinician;³¹

- 4) Becoming afebrile within 1-3 days of commencing intravenous antibiotics, with improved respiratory symptoms and signs, $\text{SpO}_2 \geq 92\%$ in air and are ready to be switched to oral amoxicillin-clavulanate; and
- 5) Had symptoms for ≤ 7 -days at the time of admission to hospital.

Exclusion criteria are: (1) current wheeze (during hospitalisation); (2) underlying co-morbidities other than asthma (e.g. bronchiectasis, cyanotic congenital heart disease, cardiac failure, neuromuscular disorders, immunodeficiency) that could potentially influence the current illness; (3) severe malnutrition (weight-for-height Z-score < -3.0); (4) complicated pneumonia (effusion, empyema or abscess, tuberculosis) and/or where pathogens are identified that require different antibiotics or extended courses of treatment (eg. *Staphylococcus aureus*, *Burkholderia pseudomallei*, *Mycobacterium tuberculosis* or *Mycoplasma pneumoniae*); (5) concurrent extra-pulmonary infection requiring additional antibiotic therapy (e.g. meningitis); (6) penicillin allergy; (7) enrolled in the study previously; or (8) unable to return for follow-up clinic visits during the next 24-months.

Recruitment

Eligible children with radiographic-confirmed pneumonia are identified by a member of the research team visiting the paediatric wards of each hospital twice-daily. Within 24- hours of admission to the paediatric ward, the parent/guardian of a potentially eligible child is approached. A member of the research team discusses the study with the parent/guardian in detail using the consent flipchart, information booklet and interpreters (where appropriate). After all aspects of study are explained, including potential risks and benefits,

written informed consent is obtained from parents/guardians who agree to participate in the study. Each site maintains a screening log with limited details recorded [screening number, date, age and sex of the person, whether informed consent was obtained or reason for refusal (if the participant wishes to provide that information)].

During hospitalisation, children with uncomplicated segmental or lobar pneumonia receive 1-3 days of intravenous site-specific antibiotics (either ampicillin or benzylpenicillin G according to the hospital's protocol) and oxygen supplementation if SpO2 in air $\leq 92\%$. Other clinical management (e.g. intravenous fluids, antipyretics, nutritional support) is at the discretion of the treating paediatrician. The eligibility of children who have been consented is reassessed when they are ready to "step down" from intravenous to oral antibiotics. In children not eligible for randomisation (i.e. not meeting the full eligibility criteria), the parent/guardian is advised that their child will be managed in accordance with the treating hospital team's routine pneumonia protocol. Those meeting the inclusion criteria are then enrolled into the RCT and randomised to one of the two treatment arms that follow on from the 3-days of oral amoxicillin-clavulanate received by all trial participants.

Randomisation and allocation

The randomisation sequence was computer-generated and used random permuted block sizes of 4 to 8, prepared by a statistician external to the study team. Treatment groups are allocated according to the randomisation code. Upon enrolment, the child is assigned to the next unique number on the appropriate stratified list. The allocation is performed by the trial pharmacist at the respective hospitals. Randomisation is stratified by city site (Darwin, Auckland, Kota Kinabalu, Kuching, Kuala Lumpur, Klang) and age (<1 or 1-5 years). The allocation sequence

is concealed, and will not be revealed until data analyses are complete.

Treatment groups and blinding

After ceasing intravenous antibiotics and completing the 3-days of oral amoxicillin-clavulanate 400/57 duo suspension formulation (80mg/kg/day of the amoxicillin component in two divided doses), the children randomised to one of two treatment groups will receive either: (1) in the active arm: 8-days of oral amoxicillin-clavulanate 400/57 duo suspension (80mg/kg/day of amoxicillin component in two divided doses; max 980 mg per day); or (2) in the control arm: 8-days of oral placebo suspension (in two divided doses in volumes equal to the active arm). The placebo medication, manufactured specifically by the Institute of Drug Technology Australia Limited (Melbourne, Victoria), has an indistinguishable taste, smell, texture and appearance to the active medication, as used previously.³² Both the active antibiotic and placebo are in matched opaque bottles. For all trial medications, equal volumes of water are added using a syringe in a child-safety, sealed, opaque bottle. Thus, blinding of the child's allocation group will be maintained throughout the trial until the analyses is complete. Unblinding will be only be permissible if a serious adverse event occurs and we are requested by the independent data monitoring committee (iDMC) to unblind the child's allocated group.

Data collection

Data are collected from the parent/guardian and from the medical records at baseline (enrolment), 4-weeks, 12- and 24-months post-hospital discharge. On enrolment, demographic information (age, sex, ethnicity, household size, etc), birth history, breast-feeding history, prior illness, immunisation record, in-utero and household smoke exposure are recorded, and a physical examination performed by trained research staff. Immunisation data are collected from the respective country's immunisation register or patients' records. All data are documented

on hard copy standardised forms and entered into the database at a later date. De-identified data in the central database is password protected and confidentiality maintained. Electronic forms are not used because of the instability of the internet connection at some sites. The final dataset will be accessible to each site’s principal investigators, the grant holders, iDMC and the study statistician.

As with our previous RCTs,^{33,34} children are prospectively followed after being discharged from hospital. In the current study, follow-up is for 24-months post-hospital discharge with clinical reviews at the hospital or local health clinics at 4-weeks, 12- and 24-months. The primary and secondary outcome measures are collected at the time points below. Serious and non-serious (nausea, vomiting, diarrhoea, rash) adverse-events are documented and monitored. Safety exit points are discussed below. Adherence is assessed by parent report and return of empty bottles.

Specimen collection

At enrolment (baseline), as close as possible to the day of admission, and again at 4-weeks and 12-months following hospital admission for pneumonia, all children will have nasopharyngeal swabs taken, which are placed immediately into skim milk tryptone glucose glycerol broth medium and kept cold until stored at -80°C.

Routine blood collection (i.e. full blood count and blood cultures) are undertaken by the treating hospital medical team upon admission and these data are recorded. Also, CXRs are performed at admission (in all cases) and at 4-weeks and 12-months when possible (i.e. some children living in remote regions are unable to travel to the treating hospital for a CXR).

Treatment failure and exit criteria during the study

Monitoring of adverse and serious adverse events are undertaken throughout the trial using standardised adverse and serious adverse event forms. Treatment failure and exit criteria are defined as occurrence within 4-weeks of enrolment of any of the following: (1) death, (2) secondary fever ($>38^{\circ}\text{C}$) with new signs of clinical pneumonia or (3) new CXR changes. Participants are discontinued from the study protocol if the parent/guardian withdraws consent for participation, the child or parent/guardian are unable to comply with study procedures, or if a trial medication-related serious adverse event or exit criterion occurs.

Outcome measures

Our primary outcome is the proportion of children without chronic respiratory symptoms/signs or bronchiectasis³⁵ at 24-months following hospitalisation for pneumonia. Our secondary outcomes are: (1) the proportion with clinical cure (i.e. complete resolution of respiratory symptoms and signs) at 4-weeks; (2) time-to-next respiratory-related hospitalisation; (3) CXR abnormalities and; (4) adverse events. Our secondary laboratory outcomes are nasopharyngeal respiratory bacterial pathogens and antibiotic resistance (4-weeks, 12-months).

Similar to our other intervention RCTs,^{32-34,36} medical record review at community health centres and each of the hospital sites will identify respiratory rehospitalisation episodes and prior investigations for chronic lung diseases, including radiographic investigations for bronchiectasis. Additionally, parents will be specifically asked about rehospitalisations and whether a chest CT scan has been undertaken, which will be verified with checking medical records.

CXRs are digitised and anonymised. These will be scored independently by two people (respiratory physicians or radiologist) in a blinded manner. CXR abnormalities on follow-up will be dichotomised into abnormal (presence of new or persistent parenchymal densities or infiltrates)^{31,37} or normal. Disagreements will be resolved by consensus.

The stored nasopharyngeal swabs will be processed as done previously.^{32,36} Briefly, batches of swabs will be thawed and cultured on selective media. *Streptococcus pneumoniae*, *Haemophilus influenzae*, *Moraxella catarrhalis* and *S. aureus* will be confirmed by standard techniques.^{36,38} Based upon their colonial morphology, four isolates each of *S. pneumoniae*, *H. influenzae*³⁸ and *S. aureus* will have their antibiotic susceptibilities determined by the calibrated susceptibility disc diffusion method.³⁶ The minimum inhibitory concentration for penicillin for *S. pneumoniae* will be determined by E-tests if the oxacillin disc zone is <6mm; and for *H. influenzae* if the ampicillin disc zone is <6mm.³⁶ The European Committee on Antimicrobial Susceptibility Testing criteria will identify resistant isolates. A nitrocephin-based test will detect beta-lactamase activity in *H. influenzae* and *M. catarrhalis* isolates.

Sample size

Sample size estimates are based on our primary outcome (proportion without chronic respiratory symptoms/signs or bronchiectasis at 24-months). We wish to detect a significant difference between the active arm (i.e. longer antibiotic course) and the control arm (i.e. shorter antibiotic course). We assume the percentage without chronic respiratory morbidity (at 24-months) in the short antibiotic group (controls) is 65.9% (based on our previous Central Australian pneumonia study³¹ where 34.1% had persistent respiratory morbidity at 12-months). To find a 50% reduction in bronchiectasis (or chronic respiratory symptoms), the percentage without bronchiectasis in the long antibiotic group will be 82.9%. For 89% power and

alpha=0.05, we require outcome data from 131 patients in each treatment group. Adding 20% (for participant drop-out), we will enrol 157 children in each group. To mitigate the possibility of an even higher drop-out rate, we will replace participants that missed the 12-month follow-up, until late 2019. Replacements will be assigned a new identification number and treatment allocation.

Statistical analyses and reporting

Data coding and entry is based at Darwin and conducted in accordance with good clinical practice. Data will be reported and presented in accordance with the updated CONSORT criteria.³⁹ Children will be analysed according to the intention-to-treat principle where analysis will be by allocation status regardless of subsequent management. A detailed statistical analysis plan that is approved by the iDMC will be in place prior to data analyses.

For our primary aim, the main effects of the intervention will be determined by comparing the proportion without any chronic respiratory symptoms/signs or evidence of bronchiectasis at 24-months. We will report relative risk calculated via log-binomial regression models. Generalised linear models will be used to calculate absolute differences between proportions (with 95%CI), as in previous analyses.^{32,36}

For our secondary aims, the effects of the interventions will be determined by: (1) comparing the proportion with clinical cure (complete resolution of respiratory symptoms and signs) at 4-weeks and; (2) constructing a Kaplan-Meier curve for each group for time-to-next respiratory-related hospitalisation, and proportions will be compared using the log-rank test as well as time-to-event regression models (as above). Logistic regression will be used to examine the effects of treatment duration upon respiratory bacterial pathogen colonisation in the

nasopharynx and antibiotic resistance with models adjusted for potentially confounding demographic, social and clinical variables as appropriate, as done previously.^{32,36} CXR abnormality data will be compared between children with and without chronic respiratory symptoms/bronchiectasis. CXR abnormalities will be dichotomised (present/absent) and χ^2 tests used to determine the OR with 95% CIs for presence of chronic symptoms/bronchiectasis.

Patient and public involvement

The study was discussed with, and approved by, the Indigenous Reference Group (Darwin) prior to submitting the grant applications and beginning the study. Also, the study was discussed with, and approved by, the Māori Research Review Committee (Auckland) prior to submitting the New Zealand-based grant application and commencement of the study in New Zealand in 2017. Patients were not involved in the study question or design, but the above committees members have family members who have had pneumonia as children, and they approved of the study design and outcome measures.

Ethics, dissemination and safety monitoring

The Human Research Ethics Committees of all the recruiting institutions (Darwin: Northern Territory Department of Health and Menzies School of Health Research; Auckland: Starship Children’s and KidsFirst Hospitals; East Malaysia: Likas Hospital and Sarawak General Hospital; Kuala Lumpur: University of Malaya Research Ethics Committee; and Klang: Malaysian Department of Health) have approved the research protocol version 7 (13 Aug 2018).

We will publish the results in a major medical journal (using the ICMJE author guidelines), and share the outcomes with the academic and medical community, funding and relevant

patient organisations. Professional writers will not be used. All adverse events, including serious adverse events, are monitored by an iDMC, which was established and met prior to commencing the study. An Indigenous Reference Group oversees the cultural aspects of the study.

Discussion

We are currently undertaking a multicentre, double-blind RCT in three countries to address the question of whether a longer course of antibiotics (13-14 days), compared to the standard short course (5-6 days), for treating young children hospitalised with community-acquired pneumonia (assumed by fulfilling the inclusion criteria to be of bacterial origin) reduces its long-term complications. The biological plausibility of our hypothesis was presented above. The outcomes and time points were chosen carefully as described below.

Many factors influence the prevalence of infectious agents associated with pneumonia. These include: (a) patient factors (e.g. age, nutritional state, co-morbidities, immunisations received), (b) the timing, site and nature of specimens taken (c) the type and depth of laboratory tests used, and (d) the nature and intensity of exposure to circulating microorganisms (e.g. crowding, household and external air pollution, seasons, community use of antibiotics).^{11,40} As our study settings differ, it is unknown whether bacterial causes of pneumonia vary between the sites. Nevertheless, in the context of the difficulty in ascribing aetiology of pneumonia when blood cultures are negative and without direct lung samples, we did not aim to undertake an aetiology study.

Rationale for our chosen outcome measures and time frame

Chronic cough (defined as >4-weeks duration^{41,42}) can occur post-ALRIs.⁴³ In children, chronic cough has an often unrecognised high morbidity,⁴⁴ may reflect the underlying cause,⁴⁵ and is the dominant symptom of bronchiectasis.²⁷ In a national study, we found that 9% of 346 children newly-referred for chronic cough had bronchiectasis, which was significantly more likely in Indigenous than non-Indigenous children (OR 4.4, 95%CI 1.9, 10.0).⁴⁵ Further, our follow-up study of young children hospitalised for bronchiolitis identified that the persistence of cough at 3-4 weeks post-discharge significantly increased the OR of having bronchiectasis detected at a median of 13-months post-index hospitalisation.⁴⁶ Also, our earlier study observed that of 109 Indigenous NT children hospitalised with CXR-proven pneumonia, of whom 90 (83%) were reviewed at 12-months, 23/90 (26%) had a new treatable chronic respiratory illness.³¹ Finally, in a New Zealand study,⁴⁷ 94/164 (74%) (86% Māori/Pacifica) infants and young children hospitalised before age 2-years for bronchiolitis (44%) or pneumonia (56%) underwent a clinical review 12-months later where 81 also had a repeat CXR. Overall, in the follow-up cohort 29/94 (31%) had a chronic wet cough history, 30 (32%) still had a cough with or without chest crackles on examination and 50/81 (62%) had pulmonary infiltrates present.⁴⁷ Thus, we chose these chronic cough, evaluated at 4-weeks, 12- and 24-months post-hospitalisation for pneumonia, and CXR changes at the two earlier timepoint, as they are important markers for future lung health.

Rationale for amoxicillin-clavulanate

Amoxicillin is the recommended oral antibiotic for treating non-severe pneumonia in young children aged <5-years from both high and low-to-middle income countries.^{1,30} Our original intention was to use amoxicillin as ‘step-down’ therapy in the RCT, but unfortunately the cost of preparing and manufacturing its placebo proved prohibitive. Instead, we chose amoxicillin-clavulanate, since from our previous studies it was well tolerated and importantly we had both

access and guaranteed supply of a validated placebo medication, indistinguishable from the active antibiotic.^{32,48} Because of its broader-spectrum of action, amoxicillin-clavulanate is recommended as a second-line agent for inpatient and outpatient treatment of pneumonia.^{1,30} Nevertheless, a recent survey of 19 hospitals in 16 European countries identified it was used as a first-line antibiotic by more than 25% of centres for treating paediatric community-acquired pneumonia in both hospital and community settings.⁴⁹ Amoxicillin-clavulanate offers the theoretical advantage of activity against β -lactamase producing strains of *H. influenzae* and *M. catarrhalis* that heavily colonise the upper airways of these young children and may play a role in establishing chronic lung disease following an episode of severe pneumonia.^{4,12} The accompanying risk of course is selecting antibiotic-resistant organisms. To this end we are monitoring antibiotic susceptibility patterns of nasopharyngeal respiratory bacterial pathogens 4-weeks and 12-months after commencing treatment for pneumonia. The nasopharynx was chosen because of its relative ease of sampling access and as it acts as reservoir for transmitting antibiotic-resistant respiratory bacterial pathogens within the community.⁵⁰

In summary, our study addresses a large knowledge gap of a common worldwide problem in early childhood pneumonia. The multicentre nature of our study increases the generalisability of the future findings of our RCT that is complemented by assessing predictors of future morbidity.

Authors' contributions

AC conceived and designed the study, drafted the manuscript and was primarily responsible for obtaining the grant. KG co-conceived and designed the study, had a major input into the grant submission and edited the manuscript. RW led the statistical components for grant submission. JU, SF, TY, MO, AN, JdB, PM, BL, PT contributed to study design, grant

submission and manuscript. CB is the lead investigator at the Auckland site and obtained a 2-year grant for recruiting the children in New Zealand. SF is the lead investigator in Kota Kinabalu, MO is the lead investigator in Kuching, AN is the lead investigator in Kuala Lumpur and obtained a Malaysian grant that supported the study in Kuala Lumpur. NN and NS are the lead investigators at the Klang site. GM initiated the project, prepared the SOPs, submitted the ethics application and is currently coordinating all aspects of the project. HSV leads the laboratory component of assessing nasopharyngeal bacteria and its resistance to antibiotics. All authors read and approved the final manuscript.

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Competing interests statement: The authors declare that they have no financial competing interests.

Figure legend

Overall schematic study design.

Abbreviations: ABs, antibiotics; CXR, chest x-ray; NPS, nasopharyngeal swab.

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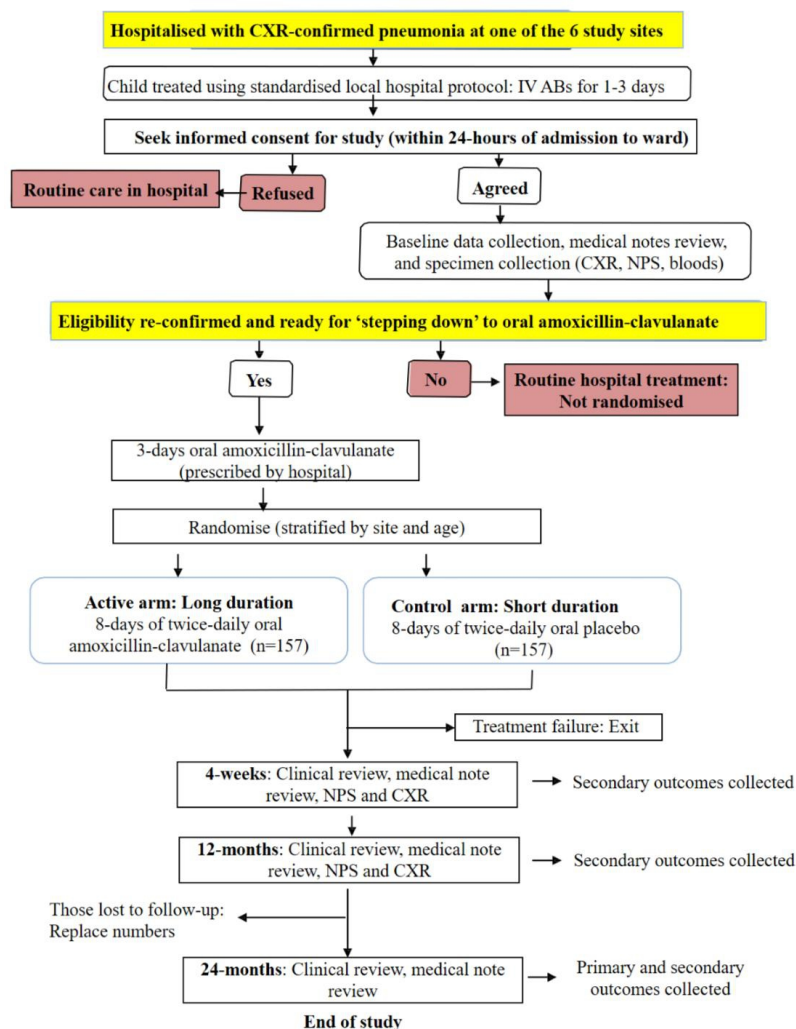


Figure 1

94x139mm (300 x 300 DPI)



SPIRIT 2013 Checklist: Recommended items to address in a clinical trial protocol and related documents*

Section/item	Item No	Description	Addressed on page number
Administrative information			
Title	1	Descriptive title identifying the study design, population, interventions, and, if applicable, trial acronym	___ 1 ___
Trial registration	2a	Trial identifier and registry name. If not yet registered, name of intended registry	___ 4 ___
	2b	All items from the World Health Organization Trial Registration Data Set	___ NA ___
Protocol version	3	Date and version identifier	___ 16 ___
Funding	4	Sources and types of financial, material, and other support	___ 20 ___
Roles and responsibilities	5a	Names, affiliations, and roles of protocol contributors	___ 19 ___
	5b	Name and contact information for the trial sponsor	___ 20 ___
	5c	Role of study sponsor and funders, if any, in study design; collection, management, analysis, and interpretation of data; writing of the report; and the decision to submit the report for publication, including whether they will have ultimate authority over any of these activities	20 _____
	5d	Composition, roles, and responsibilities of the coordinating centre, steering committee, endpoint adjudication committee, data management team, and other individuals or groups overseeing the trial, if applicable (see Item 21a for data monitoring committee)	___ 20 ___

1	Introduction			
2				
3	Background and	6a	Description of research question and justification for undertaking the trial, including summary of relevant	4-7
4	rationale		studies (published and unpublished) examining benefits and harms for each intervention	
5				
6		6b	Explanation for choice of comparators	17-20
7				
8	Objectives	7	Specific objectives or hypotheses	7-8
9				
10	Trial design	8	Description of trial design including type of trial (eg, parallel group, crossover, randomised trial, single group),	8
11			allocation ratio, and framework (eg, superiority, equivalence, noninferiority, exploratory)	
12				
13				
14	Methods: Participants, interventions, and outcomes			8
15				
16	Study setting	9	Description of study settings (eg, community clinic, academic hospital) and list of countries where data will	
17			be collected. Reference to where list of study sites can be obtained	
18				
19	Eligibility criteria	10	Inclusion and exclusion criteria for participants. If applicable, eligibility criteria for study centres and	8-9
20			individuals who will perform the interventions (eg, surgeons, psychotherapists)	
21				
22	Interventions	11a	Interventions for each group with sufficient detail to allow replication, including how and when they will be	8-9
23			administered	
24				
25		11b	Criteria for discontinuing or modifying allocated interventions for a given trial participant (eg, drug dose	10-11
26			change in response to harms, participant request, or improving/worsening disease)	
27				
28		11c	Strategies to improve adherence to intervention protocols, and any procedures for monitoring adherence	11
29			(eg, drug tablet return, laboratory tests)	
30				
31		11d	Relevant concomitant care and interventions that are permitted or prohibited during the trial	11-12
32				
33	Outcomes	12	Primary, secondary, and other outcomes, including the specific measurement variable (eg, systolic blood	13-14
34			pressure), analysis metric (eg, change from baseline, final value, time to event), method of aggregation (eg,	
35			median, proportion), and time point for each outcome. Explanation of the clinical relevance of chosen	
36			efficacy and harm outcomes is strongly recommended	
37				
38	Participant timeline	13	Time schedule of enrolment, interventions (including any run-ins and washouts), assessments, and visits for	Fig 1 and 11-12
39			participants. A schematic diagram is highly recommended (see Figure)	
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1	Sample size	14	Estimated number of participants needed to achieve study objectives and how it was determined, including clinical and statistical assumptions supporting any sample size calculations	____ 14 ____
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3				
4	Recruitment	15	Strategies for achieving adequate participant enrolment to reach target sample size	____ 9-10 ____
5				
6	Methods: Assignment of interventions (for controlled trials)			
7				
8	Allocation:			
9				
10	Sequence generation	16a	Method of generating the allocation sequence (eg, computer-generated random numbers), and list of any factors for stratification. To reduce predictability of a random sequence, details of any planned restriction (eg, blocking) should be provided in a separate document that is unavailable to those who enrol participants or assign interventions	____ 10-12 ____
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16	Allocation concealment mechanism	16b	Mechanism of implementing the allocation sequence (eg, central telephone; sequentially numbered, opaque, sealed envelopes), describing any steps to conceal the sequence until interventions are assigned	____ 10-12 ____
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20	Implementation	16c	Who will generate the allocation sequence, who will enrol participants, and who will assign participants to interventions	____ 10-12 ____
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24	Blinding (masking)	17a	Who will be blinded after assignment to interventions (eg, trial participants, care providers, outcome assessors, data analysts), and how	____ 11 ____
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26				
27		17b	If blinded, circumstances under which unblinding is permissible, and procedure for revealing a participant's allocated intervention during the trial	____ 12-13 ____
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31	Methods: Data collection, management, and analysis			
32				
33	Data collection methods	18a	Plans for assessment and collection of outcome, baseline, and other trial data, including any related processes to promote data quality (eg, duplicate measurements, training of assessors) and a description of study instruments (eg, questionnaires, laboratory tests) along with their reliability and validity, if known. Reference to where data collection forms can be found, if not in the protocol	____ 11-12 ____
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39		18b	Plans to promote participant retention and complete follow-up, including list of any outcome data to be collected for participants who discontinue or deviate from intervention protocols	____ 12-13 ____
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1	Data management	19	Plans for data entry, coding, security, and storage, including any related processes to promote data quality (eg, double data entry; range checks for data values). Reference to where details of data management procedures can be found, if not in the protocol	15
2				
3				
4				
5	Statistical methods	20a	Statistical methods for analysing primary and secondary outcomes. Reference to where other details of the statistical analysis plan can be found, if not in the protocol	15
6				
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8		20b	Methods for any additional analyses (eg, subgroup and adjusted analyses)	15
9				
10		20c	Definition of analysis population relating to protocol non-adherence (eg, as randomised analysis), and any statistical methods to handle missing data (eg, multiple imputation)	15
11				
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13				
14	Methods: Monitoring			
15				
16	Data monitoring	21a	Composition of data monitoring committee (DMC); summary of its role and reporting structure; statement of whether it is independent from the sponsor and competing interests; and reference to where further details about its charter can be found, if not in the protocol. Alternatively, an explanation of why a DMC is not needed	20
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21		21b	Description of any interim analyses and stopping guidelines, including who will have access to these interim results and make the final decision to terminate the trial	15
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25	Harms	22	Plans for collecting, assessing, reporting, and managing solicited and spontaneously reported adverse events and other unintended effects of trial interventions or trial conduct	13
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28	Auditing	23	Frequency and procedures for auditing trial conduct, if any, and whether the process will be independent from investigators and the sponsor	NA
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32	Ethics and dissemination			
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34	Research ethics approval	24	Plans for seeking research ethics committee/institutional review board (REC/IRB) approval	16
35				
36				
37	Protocol amendments	25	Plans for communicating important protocol modifications (eg, changes to eligibility criteria, outcomes, analyses) to relevant parties (eg, investigators, REC/IRBs, trial participants, trial registries, journals, regulators)	16
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Consent or assent	26a	Who will obtain informed consent or assent from potential trial participants or authorised surrogates, and how (see Item 32)	9-10
	26b	Additional consent provisions for collection and use of participant data and biological specimens in ancillary studies, if applicable	NA
Confidentiality	27	How personal information about potential and enrolled participants will be collected, stored, shared, and maintained in order to protect confidentiality before, during, and after the trial	12
Declaration of interests	28	Financial and other competing interests for principal investigators for the overall trial and each study site	20
Access to data	29	Statement of who will have access to the final trial dataset, and disclosure of contractual agreements that limit such access for investigators	12
Ancillary and post-trial care	30	Provisions, if any, for ancillary and post-trial care, and for compensation to those who suffer harm from trial participation	NA
Dissemination policy	31a	Plans for investigators and sponsor to communicate trial results to participants, healthcare professionals, the public, and other relevant groups (eg, via publication, reporting in results databases, or other data sharing arrangements), including any publication restrictions	16
	31b	Authorship eligibility guidelines and any intended use of professional writers	16
	31c	Plans, if any, for granting public access to the full protocol, participant-level data, and statistical code	NA
Appendices			
Informed consent materials	32	Model consent form and other related documentation given to participants and authorised surrogates	uploaded
Biological specimens	33	Plans for collection, laboratory evaluation, and storage of biological specimens for genetic or molecular analysis in the current trial and for future use in ancillary studies, if applicable	NA

*It is strongly recommended that this checklist be read in conjunction with the SPIRIT 2013 Explanation & Elaboration for important clarification on the items. Amendments to the protocol should be tracked and dated. The SPIRIT checklist is copyrighted by the SPIRIT Group under the Creative Commons “Attribution-NonCommercial-NoDerivs 3.0 Unported” license.