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Pulse oximetry and oxygen services for under-five children with community-acquired pneumonia attending primary and secondary level health facilities in Lagos, Nigeria (INSPIRING-Lagos): a pre-implementation and post implementation study

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ABSTRACT

Introduction Childhood pneumonia is a leading cause of child mortality in Nigeria and poor quality of care is a persistent issue. We aimed to understand whether introducing primary care stabilisation rooms equipped with pulse oximetry and oxygen systems alongside healthcare worker (HCW) training improved the quality of care for children with pneumonia in Lagos State.

Methods *Setting*: Ikorodu local government area, Lagos. *Population*: children aged 0–59 months with clinically diagnosed pneumonia. *Intervention*: establishment of 'stabilisation rooms' within government (n=7) and private (n=7) primary care facilities, designed for short-term oxygen delivery for hypoxaemic children prior to hospital transfer, alongside HCW training on integrated management of childhood illness (IMCI), pulse oximetry and oxygen therapy. Two secondary facilities with inpatient oxygen systems received training and pulse oximeters. *Primary outcome*: composite 'correct management' of hypoxaemic pneumonia including oxygen therapy administration, referral and admission to hospital. *Analysis*: mixed-effects logistic regression comparing baseline (September 2020–August 2021) and implementation (September 2021–November 2022) periods, adjusted for clustering by facility.

Results We screened 20 158 children, of which 160 children with hypoxaemic pneumonia (SpO_2<90%) were recruited. The proportion of hypoxaemic children with 'correct management' remained low and unchanged: 9/98 (9%) with data on referral and admission at baseline, and 6/52 (12%) during implementation (mixed effects logistic regression adjusted OR (aOR): 1.17 (95% CI 0.30, 4.52), p=0.822). Oxygen use for children with hypoxaemia increased from baseline 10/105 (10%) to 13/55 (24%) during implementation (aOR 3.01 (95% CI 1.05, 8.65), p=0.040). But subsequent referral and hospital admission remained low. Low pulse oximetry use by health workers in children with clinical pneumonia persisted through baseline (73/798, 9%) and implementation (122/1125, 11%).

Conclusion Equipping primary care stabilisation rooms with pulse oximetry and oxygen increased oxygen use for children with hypoxaemia but did not improve referral or hospital admission rates. Persistent failure to assess children with pulse oximetry likely contributed to under-recognition of hypoxaemia and therefore failure to initiate correct care. Further work to improve initial triage, assessment and treatment of children with severe pneumonia in Lagos is urgently needed.

Trial registration number ACTRN12621001071819.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Childhood pneumonia remains a leading cause of child mortality globally with many children dying because they are not identified as having low blood oxygen saturation (being hypoxaemic) and are not treated with oxygen.

⇒ How best to improve early identification of hypoxaemic children and expand access to oxygen treatment, including in primary care, remain pressing questions to address to reduce this burden.

WHAT THIS STUDY ADDS

⇒ We found that equipping primary care stabilisation rooms with oxygen and training health workers increased the proportion of hypoxaemic pneumonia cases treated with oxygen but failed to impact subsequent referral and hospital admission practices.

⇒ Persistent failure to assess children with pulse oximetry likely contributed to under-recognition of hypoxaemia and therefore failure to initiate correct care.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ These findings provide evidence of improvement in the care of hypoxaemic children, and identify key gaps for subsequent work to address.

⇒ Overcoming barriers to early diagnosis of hypoxaemic children and to expanding access to oxygen treatment requires further work building on the findings of this study. This should include work to understand extrinsic and intrinsic incentives for health workers to do pulse oximetry in primary care, and ensure children stabilised with oxygen in primary care are subsequently referred and admitted for inpatient oxygen treatment and supportive care.

INTRODUCTION

Under-five child mortality in Nigeria remains among the highest in the world at 102 per 1000 live births in 2021.[1] Pneumonia is a leading cause of child mortality in Nigeria. Under-five child mortality varies considerably between states, with Lagos State having the lowest estimated rate at 15 per 1000 live births in 2021.[1] However, given Lagos' population of 13.4 million in 2021 of which 2.8% are under one,[1] this equates to over 5000 deaths each year. Lagos State has relatively less poverty than other states in Nigeria, with only 1.6% of the population being in the lowest three wealth quintiles.[1] Despite its relative advantages, quality of care, including that for treatment of pneumonia, remains an issue in Lagos State.[2–5]

Pulse oximetry is used to measure oxygen saturation of peripheral blood (SpO_2) and detect hypoxaemia (low blood oxygen saturation). Hypoxaemia is associated with paediatric mortality, independent of other clinical signs.[6 7] Pulse oximetry is therefore an important diagnostic tool, though implementation in low-resource contexts and particularly at primary care levels remains low, including in Lagos.[8] A recent Delphi study on paediatric pneumonia research priorities identified questions around the integration of pulse oximetry into integrated management of childhood illness (IMCI) and existing protocols, and the effects of pulse oximetry on referrals and time to treatment, as high priority.[9] Hypoxaemia is treated with oxygen and typically requires inpatient admission for further assessment and management of the underlying cause. Therefore, pulse oximetry needs to be accompanied by access to oxygen therapy and effective referral and admission pathways. Pulse oximetry and oxygen therapy can be provided by non-physician clinicians, but we know little about how to implement them in primary care settings for stabilisation of patients before referral to secondary inpatient care.[8 9]

The Integrated Sustainable Reduction in Childhood Pneumonia and Infectious Diseases in Nigeria (INSPIRING) programme aimed to tackle childhood pneumonia through context-sensitive targeted interventions in Jigawa State,[10] and Lagos State.[11] The approaches in the two states were different and tailored to the specific needs of the contexts. In Lagos, the programme was a health service improvement project focused on increasing the capacity of primary care providers to manage pneumonia cases through the introduction of 'stabilisation rooms' alongside clinical education.[11] This paper reports the INSPIRING-Lagos impact evaluation, an evaluation of a health service improvement project assessing the impact of the stabilisation room intervention on 'correct management' of hypoxaemic pneumonia (including stabilisation with oxygen therapy, referral and subsequent attendance to hospital). We also evaluated secondary outcomes of mortality and pulse oximetry coverage.

METHODS

Design

We conducted an uncontrolled before-after quasi-experimental study, evaluating the effect of establishing primary care stabilisation rooms on management of children with hypoxaemic pneumonia. The baseline period was defined as 1 September 2020 to 31 August 2021, and the implementation period as 1 September 2021 to 30 November 2022.

Study setting

Our study was done across 16 health facilities in Ikorodu local government area (LGA), a peri-urban context in Lagos, with relative poverty: seven government primary health centres (PHC), seven private health facilities and two government secondary facilities (figure 1). The seven government PHC facilities were purposively chosen as those in greatest need of oximetry and oxygen. The seven private facilities were then selected purposefully, by matching on closest geographic location to a PHC, and restricted to those providing care to under-five children and consented to take part in the study.[11] While oxygen services are free to patients at government PHC they are relatively expensive at secondary and private facilities in this setting.[8] In addition to out-of-pocket payments, we also found common barriers to care in this context to be 'challenges in effective communication with caregivers, delayed presentation, and lack of clear diagnosis, and case management guidelines'.[2]

Description of interventions delivered

The 'stabilisation room' intervention was co-designed by research, implementing and government partners, following a situational analysis our team undertook,[2–5] as explained in our protocol paper.[11] Stabilisation rooms were implemented by Save the Children Nigeria and the Lagos State government Ministry of Health as a multicomponent intervention package including: (1) pulse

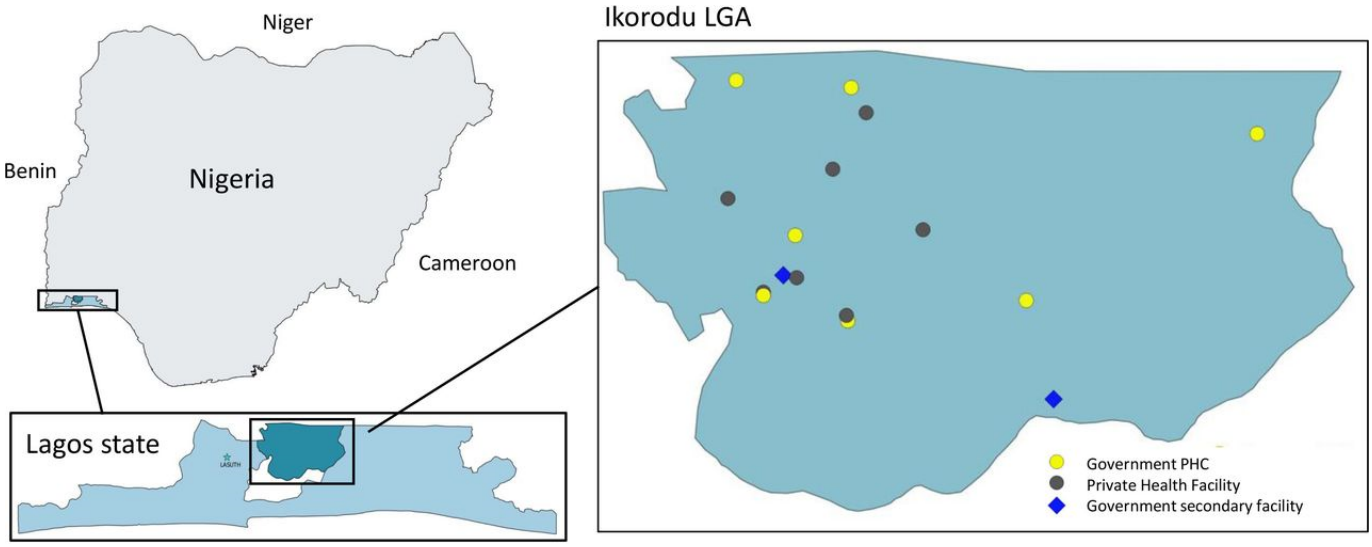

Figure 1 Map of study clinics. LGA, local government area; PHC, primary health centre.

oximeters; (2) medical oxygen delivered through newly installed oxygen concentrators powered from mains supply, generators and/or solar power; and (3) clinical guidelines, job aids, clinical training, mentoring and supervision (details in table 1). These stabilisation rooms involved modification of existing observation rooms and were intended to stabilise hypoxaemic patients with oxygen before referral, as per IMCI policy, to a secondary facility. Secondary facilities were provided with pulse oximeters, and were already equipped with inpatient oxygen systems. Prior to the intervention 65% of health-care workers (HCWs) in government PHCs and 33% in private PHCs in Ikorodu LGA reported receiving IMCI training, and 33% and 91%, respectively, reported having ever given a child oxygen therapy; few facilities surveyed had access to functional pulse oximetry (0% government PHC; 26% private PHC).[8]

Outcomes

Our *primary outcome* was a composite measure of 'correct management' of hypoxaemic (SpO_2<90%) pneumonia cases. We defined correct management as a child meeting all three of the following criteria: (1) received oxygen treatment either during hospital admission, stabilisation, or pre-referral (confirmed through medical records or care-giver report); (2) referred for admission by the HCW; (3) subsequently admitted to hospital. The rationale for our composite primary outcome is that hypoxaemic cases

Table 1 Description of intervention components

Activity	Description
Equipment provision	Each PHC and private facility received either two Lifebox (equipped with adult and paediatric clip probes) or three Masimo RadG (equipped with paediatric clip probe) pulse oximeters and one oxygen concentrator (either AirSep 10lpm or CantaMedica 5lpm), and a supply of consumables including nasal prongs. Secondary facilities each received four pulse oximeters only, as they already had functioning oxygen systems
IMCI training	Staff at all facilities received 6-day training on Integrated Management of Childhood Illness (IMCI), delivered by Ministry of Health staff from the General Hospitals and supported by Save the Children staff. Target audience: CHEW, CHO, Nurses. Training occurred 2–4 times in government facilities and 1–3 times in private facilities: April 2021 (seven government facilities), August 2021 (six government and five private facilities), April 2022 (one government and one private facility, plus both secondary facilities), August 2022 (six government and four private facilities)
Pulse oximetry and oxygen training	Staff at all facilities received 3-day training on pulse oximetry and oxygen therapy, delivered by Oxygen for Life clinical and biomedical engineering staff. Target audience: CHEW, CHO, nurses, midwives, doctors, ±technicians. Training occurred two times in all government facilities and 1–2 times in private facilities with refresher training alongside IMCI training (March 2021 to September 2022), additional on-the-job training alongside oxygen equipment installation (August 2021) and 1–4 repeat visits to support and troubleshoot
Mentoring, supervision and maintenance	Repeated mentoring and supervision visits were planned, but visits were only conducted once in November 2022, the last month of this study. Equipment audits were conducted annually by Oxygen for Life to check for functionality, and spare parts for both concentrators and oximeters were available throughout

CHEW, community health extension worker; CHO, community health officer; PHC, primary health centre.

stabilised with oxygen in primary care require subsequent referral and admission to hospital to ensure continued safe care and successful treatment outcomes, and reflects current IMCI guidelines for hypoxaemia management.

Secondary outcomes included: case fatality rate (CFR) at 2-week follow-up; correct use of pulse oximetry for screening; correct HCW treatment recommendation (as per Paediatrics Association of Nigeria recommendations for treatment of community acquired pneumonia[12]); correct diagnosis of pneumonia cases by health workers.

Data collection methods

We trained clinical data collectors in correct assessment and diagnosis of pneumonia (including pulse oximetry) to accurately identify the hypoxaemic pneumonia population, and evaluate diagnosis, treatment and clinical outcomes for pneumonia patients before and during implementation of the INSPIRING-Lagos intervention. Clinical data collectors were qualified nurses, and received training at the start of the project by clinical project staff, and were re-trained two times (January 2021, July 2021), and supervised by the Lagos Project Manager. Following formative work where we observed few pneumonia diagnoses by HCWs despite clinically evident signs,[2] we consider our clinical data collectors to be a better 'reference standard' for diagnosing and recording pneumonia cases. Each clinical data collector covered one to two clinics, visiting each clinic at scheduled times each week according to a monthly roster that ensured we recruited at different times and days in each facility to maximise representativeness of patients. During these scheduled clinic visits, data collectors screened all children under five who presented to the clinic with an acute illness and whose parent/caregiver consented to participate. After consent, clinical data collectors clinically assessed children for pneumonia according to the IMCI algorithm, including pulse oximetry and lung auscultation. They asked caregivers about recent exposure to COVID-19 cases and any positive SARS-CoV-2 viral tests. Children who met the IMCI pneumonia or severe pneumonia classification, or were deemed a suspected COVID-19 case, were included as our study population.

After the clinical data collector completed their assessment, children were routinely assessed by the HCW. After the HCW consultation on the day of recruitment, clinical data collectors would enquire about caregiver intentions for onward care, extract routine clinical data from the HCW's clinical notes (including diagnosis, treatment and referral decision, vital signs and clinical observations), and collect socioeconomic, vaccine history and contact information from caregivers. In cases where the HCW had not identified a child in need of urgent referral, the clinical data collectors informed the HCW and the HCW proceeded to manage the child as they deemed appropriate.

Clinical data collectors arranged for follow-up phone interviews to be conducted after 14 days. The follow-up interview confirmed survival of the child and recorded details of any onward care, oxygen received after their initial presentation, cost of care and treatment adherence. Where a child had died, clinical data collectors stopped the interview and arranged for an in-person verbal autopsy to take place, using the COVID-19-adapted WHO 2016 VA tool[13] and additional social autopsy questions around care-seeking. In cases where the clinical data collector could not complete the patient exit forms, they attempted to complete these forms at the 14-day follow-up and triangulated the information against clinical records in the facilities.

Analysis

We detail participant recruitment and inclusion in figure 2 as per Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[14] While COVID-19 was originally part of our inclusion criteria, only one case was recruited and we therefore restricted our analysis to pneumonia cases only. We present descriptive statistics, by baseline and implementation study periods, for fast breathing, chest-indrawing and danger signs pneumonia cases (as per 2005 IMCI definitions,[15] used to give a more granular picture), hypoxaemic pneumonia cases, and all pneumonia cases together including for correct diagnosis, treatment and our primary and secondary outcomes. We compare outcomes between baseline and implementation periods via two-tailed t-tests, and mixed effects logistic regression adjusting for clustering by health facility as a random effect. There were too few hypoxaemic cases each month (range 1–20, median: 6) to do the time-series regression analysis originally planned.[11]

Our primary outcome uses information from the follow-up such as caregiver reported oxygen and admission to hospital, and the analysis is therefore restricted to those with data on follow-up. Our descriptive results on presentation, diagnosis and treatment are based on data recorded in the clinics before follow-up and therefore use all the data.

Public involvement

Civil society and professional organisation representatives were involved in the co-design of the INSPIRING-Lagos project, alongside implementing partners: save the Children Nigeria and the Lagos state Ministry of Health. Additional community perspectives were sought during the situational analysis but community members had no further role in intervention design or evaluation.

RESULTS

Participant description

Figure 2 shows our STROBE[14] diagram of participant recruitment and inclusion, and participant characteristics are presented in table 2. Overall, we recruited 927 pneumonia cases (12.8% of screened children) during baseline, and 1297 (10.1% of screened children) during the implementation period. During the baseline period 29.9% of recruited cases were fast breathing pneumonia,

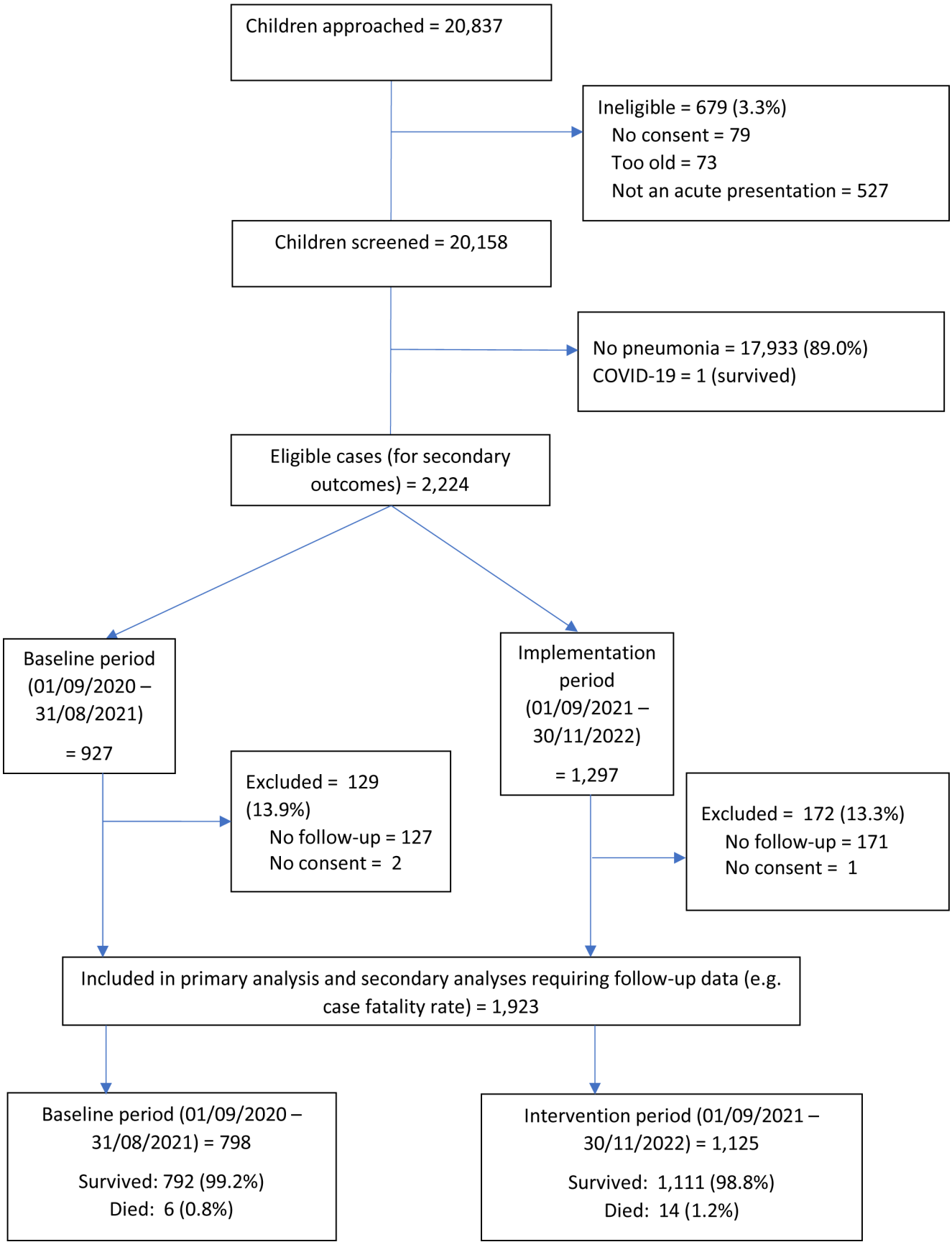

Figure 2 Participant recruitment and inclusion, Integrated Sustainable Reduction in Childhood Pneumonia and Infectious Diseases in Nigeria-Lagos study.

Table 2 Study participant characteristics during baseline and implementation periods, as documented by study clinical data collectors

Study participant characteristic	Baseline (September 20–August 2021) n (%)	Implementation (September 2021–November 2022) n (%)	P value (two-tailed t-test)	Mixed-effects logistic regression adjusted OR (95% CI), p value
Total child cases	7260	12 898		
Age (% of total child cases)				
Neonate (0–1 month)	625 (8.6%)	986 (7.6%)		
Infant (2–11 months)	2068 (28.5%)	3814 (29.6%)		
Child (12–59 months)	4567 (62.9%)	8098 (62.8%)		
Sex: female (%)	3369 (46.4%)	5996 (46.5%)		
Male (%)	3891 (53.6%)	6902 (53.5%)		
Pneumonia cases				
Pneumonia (% of total cases)	927 (12.8%)	1297 (10.1%)		
Fast breathing pneumonia (% of pneumonia cases)	277 (29.9%)	840 (64.8%)		
Chest indrawing pneumonia (% of pneumonia cases)	100 (10.8%)	197 (15.2%)		
Danger sign pneumonia (% of pneumonia cases)*	550 (59.3%)	260 (20.0%)		
Oxygen saturation measurement	**N=878/927 (94.7%)**	**N=1247/1297 (96.1%)**		
Hypoxaemic (SpO_2<90%) (N=2125)	122/878 (13.9%)	65/1247 (5.2%)	p<0.0001	0.34 (0.24, 0.47), p<0.0000
Hypoxaemic (SpO_2<90%) with oxygen treatment follow-up data (denominator for primary outcome)	105	55		
Pulse oximetry conducted by healthcare worker (% of all pneumonia cases)	85/927 (9.2%)	141/1297 (10.9%)		
Hypoxaemic cases detected by healthcare worker (% of total hypoxaemic)	19/105 (18.1%)	27/55 (49.1%)		
Oxygen treatment				
All (% of pneumonia cases)	24/927 (2.6%)	34/1297 (2.6%)		
All (% of followed up cases)	21/798 (2.6%)	33/1125 (2.9%)		
With attempted but failed oxygen saturation measurement	1	1		
Hypoxaemic (SpO_2<90%) (% of total hypoxaemic)	12/122 (10%)	14/65 (22%)	p=0.028	2.66 (1.01, 7.02) p=0.048
Hypoxaemic (SpO_2<90%) (% of hypoxaemic with oxygen treatment follow-up data)	10/105 (10%)	13/55 (24%)	p=0.016	3.02 (1.05, 8.65), p=0.040
Of which admitted	8	3		
Of which stabilised	1	5		
Of which pre-referral	0	1		
of which only caregiver reported	1	4		
And referred (% with data)	9/98 (9%)	11/52 (21%)	p=0.040	3.19 (0.94, 10.86), p=0.062
Primary outcome: oxygen treatment, referral and hospital attendance/hypoxaemic cases with data on referral and attendance	9/98 (9%)	6/52 (12%)	p=0.650	**Primary outcome:** 1.17 (0.30, 4.52), p=0.822
Case fatality				
Survival status at 14 days (2-week follow-up): total (% of pneumonia cases)	798 (86.1%)	1125 (86.7%)		
Alive (% followed up)	792 (99.3%)	1111 (98.8%)		
Dead (% followed up)	6 (0.8%)	14 (1.2%)	p=0.294	**Secondary outcome:** 1.66 (0.64, 4.35) p=0.299
Of which SpO_2<90% (% of deaths)	4 (67%)	8 (57%)		
Of which danger sign pneumonia (% of deaths)	6 (100%)	11 (78%)		

Continued

Table 2 Continued

Study participant characteristic	Baseline (September 20–August 2021) n (%)	Implementation (September 2021–November 2022) n (%)	P value (two-tailed t-test)	Mixed-effects logistic regression adjusted OR (95% CI), p value
Of which danger sign pneumonia and incorrectly treated† (% of deaths that are danger sign pneumonia)	3 (50%)	6 (55%)		

*The breakdown of danger signs for the baseline period and implementation period was similar: vomiting: baseline 218 (of 550 danger signs=39.6%), implementation 91 (of 260 danger signs=35%); no drink, no food: baseline: 53%, implementation: 37%; convulsions: baseline: 4%, implementation: 7%; unconscious: baseline: 0.4%, implementation: 0.4%; lethargic: baseline: 23%, implementation: 20%; pallor: baseline: 23%, implementation: 24%; oedema: baseline: 0.7%, implementation: 1.5%.
†Correct treatment is antibiotic treatment of fast-breathing or chest-indrawing pneumonia cases as per Paediatrics Association of Nigeria recommendations for treatment of community acquired pneumonia,[12] or immediate referral, admission to stabilisation or admission to ward of danger signs pneumonia cases. We are taking an integrated management of childhood illness perspective for primary care here and not considering oxygen, which is considered separately.

10.8% chest indrawing and 59.3% danger sign pneumonia; during the implementation period 64.8% were fast breathing, 15.2% chest indrawing and 20.0% danger sign cases. Follow-up, with data on treatment, was completed for 86.1% (n=798) of cases during baseline, and 86.7% (n=1125) during implementation. Cases lost to follow-up were not significantly different by age or sex compared with those followed up (online supplemental table 1).

Hypoxaemic pneumonia population

Our clinical data collectors captured SpO_2 data for 94.7% of pneumonia cases (n=878) during baseline and for 96.2% of pneumonia cases during implementation (n=1248; table 2). Of these 13.9% (n=122) were hypoxaemic during baseline, and 5.2% (n=65) were hypoxaemic during the implementation period (mixed effects logistic regression: OR: 0.34 in implementation period ((95% CI 0.24, 0.47), p<0.0001; table 2). A total of 105 and 55 hypoxaemic cases had complete follow-up data in the baseline and implementation periods, respectively.

The monthly proportion of hypoxaemic pneumonia cases recorded by the clinical data collectors varied over time (figure 3a), with a higher proportion of hypoxaemic cases in late 2020 and early 2021. Figure 3b shows the absolute number of cases this represents, with the highest number of hypoxaemic cases recorded in October 2020 (n=20) and January 2021 (n=20), during our baseline period. We do not have laboratory data to triangulate against, and therefore are unsure whether this was due to COVID-19 or other, seasonal, pathogens. Of note, HCWs conducted pulse oximetry assessments for only 9.2% of pneumonia cases at baseline and 10.9% during implementation (table 2). Consequently, for our primary outcome population, HCWs detected 18% (19/105) of

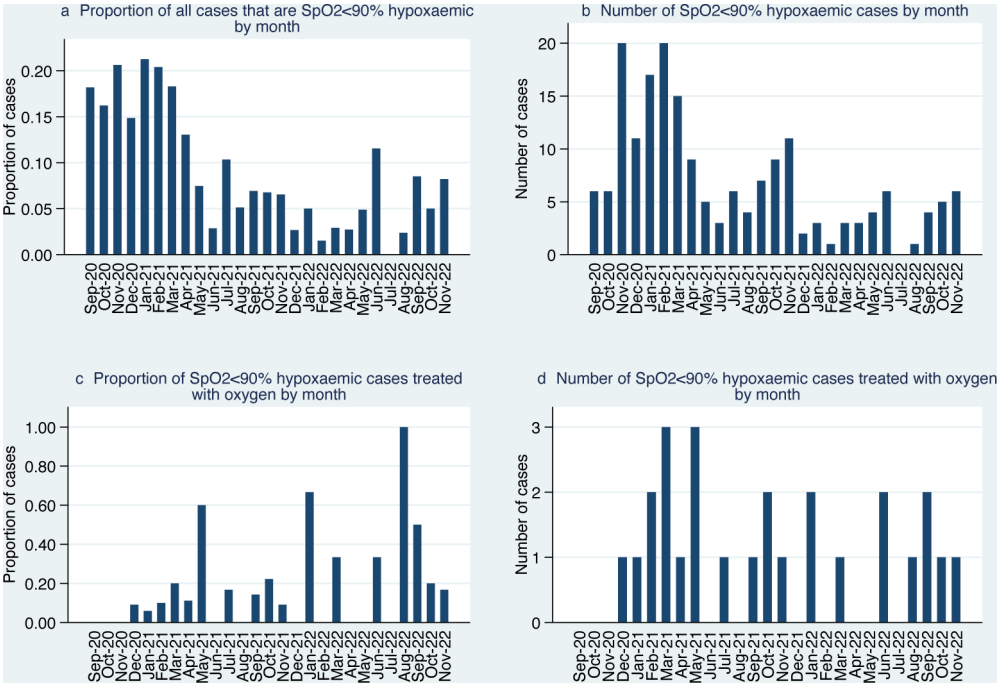

Figure 3 Clinical data collector identified hypoxaemic cases.

hypoxaemic cases at baseline and 49% (27/55) during implementation (table 2).

Primary outcome—correct management of hypoxaemic pneumonia

Our primary composite outcome of correct management—oxygen treatment, referral and admission of hypoxaemic cases—did not change from baseline (9%, 9/98) to implementation (12%, 6/52) periods (adjusted OR (aOR) 1.17 (95% CI 0.30, 4.52), p=0.822; table 2).

Breaking down this composite outcome shows some impact of the intervention on particular clinical practices.

Oxygen therapy

During baseline, 10% (10/105) of hypoxaemic cases were treated with oxygen, increasing to 24% (13/55) during the implementation period (aOR 3.02 (95% CI 1.05, 8.65), p=0.040) (figure 3c,d). Among the hypoxaemic cases who received oxygen during the baseline period, 8/10 (80%) received oxygen during hospital admission, 1/10 (10%) received it in the stabilisation room and 1/10 (10%) was only caregiver reported so the location not known. In contrast, among hypoxemic patients who received oxygen during the implementation period, 3/13 (23%) received it at hospital, 5/13 (38%) received it in the stabilisation room, 1/13 (8%) received it pre-referral and 4/13 (31%) were caregiver reported only. Oxygen treatment of hypoxaemic cases was particularly low in government PHCs (1/84, 1% at baseline) (online supplemental table 2).

Referral and admission

During baseline 9% (9/98) of hypoxaemic cases were referred and all were admitted, which increased to 21% (11/52) being referred (aOR 3.19 (95% CI 0.94, 10.86), p=0.062; table 2) and 12% (6/52) being referred and admitted. Of note, all hypoxaemic patients who were referred received oxygen therapy.

Pulse oximetry

Use of pulse oximetry by HCWs was low in the baseline and implementation periods, particularly for government PHCs (baseline 5.7%, intervention 8.7%) (online supplemental table 2). Individual facility data showed that, while pulse oximetry usage remained low for most facilities, some showed improvement (GovPHC5, GovPHC7, Private4), some were consistently high (Private3), and others deteriorated in the implementation period (GovPHC3, Private5, Secondary1)—online supplemental table 2. Compared with government facilities, HCWs at private facilities performed pulse oximetry on a greater proportion of pneumonia patients (baseline 49%, implementation 51%) and detected a higher proportion of hypoxaemic cases (online supplemental table 2). While hypoxaemia rates were similar across facility types, government PHCs saw the most children with hypoxaemic pneumonia (128/160, 80%) and had the most missed hypoxaemia diagnoses (101/114, 89%) (online supplemental table 2).

Secondary outcome—mortality

Overall, 20 deaths were recorded, 6 (CFR: 0.8%) during baseline and 14 (CFR: 1.2%) during implementation (aOR 1.66 (95% CI 0.64, 4.35), p=0.299). Of the deaths, 4/6 (67%) during baseline were hypoxaemic and 8/12 (57%) during the implementation period were hypoxaemic. 100% and 78% of the deaths were danger sign pneumonia cases in the baseline and implementation periods, respectively (table 2). Only 50% and 55% of these were correctly referred or admitted.

Correct treatment and diagnosis

We provide Sankey flow diagrams in online supplemental figure 1 to visualise the diagnosis and treatment; oxygen saturation measurement and follow-up; referral and admission for hypoxaemic cases; and, the breakdown of deaths by severity and treatment. We found that correct treatment for fast breathing, chest indrawing and danger sign pneumonia cases all increased in the implementation period compared with the baseline period (online supplemental table 3 and figure 2). However, this apparent increase was largely driven by overall increased antibiotic prescribing, including for cough and malaria, as well as acute respiratory infection and pneumonia (online supplemental table 4). The proportion of cases correctly diagnosed with pneumonia by HCWs (compared with clinical data collectors) was low in both baseline and implementation periods (online supplemental table 5 and figure 3).

Results by facility type

Online supplemental table 6 shows study participants (all cases, pneumonia cases and pneumonia cases with follow-up data) by facility and facility type for baseline and implementation periods and online supplemental table 7 details study participant characteristics and outcomes by facility type during baseline and implementation periods. Our primary outcome—treatment, referral and admission of hypoxaemic cases—showed a significant increase from baseline (0%, 0/77) to implementation (7%, 3/43) periods in government PHC (p=0.019, online supplemental table 7). We observed no change in our primary outcome between baseline and implementation periods in private (3/8, 38% to 0/1, 0%) or secondary facilities (6/13, 46% to 3/8, 38%) (online supplemental table 7).

DISCUSSION

In our before-after evaluation of a stabilisation room intervention package for primary care facilities in Ikorodu LGA, Lagos, we observed no difference in our primary outcome of 'correct management' of hypoxaemic cases. Exploration of this negative result revealed there were some improvements in hypoxaemic pneumonia case management, with increase in the proportion of hypoxaemic pneumonia cases treated with oxygen improved from 10% to 24% (p=0.040). However, we observed no impact on subsequent referral and hospital admission. This discussion explores contextual influence

on the intervention and outcomes and highlights low pulse oximetry adoption as a key factor in limiting overall effectiveness (with additional detail in our process evaluation[16]).

We observed that detection of hypoxaemia remained low, with only 49% of hypoxaemic cases diagnosed by HCWs in the implementation period. This was related to persistently low pulse oximetry usage (11% by HCWs in the implementation period), despite pulse oximetry availability and both oximetry and oxygen training. Diagnosis of pneumonia remained poor in our implementation period, also in spite of IMCI training. Given supplies of oxygen were adequate in our implementation period, our findings suggest that major contextual health systems obstacles remain[16] given 76% of hypoxaemic children were still not treated with oxygen, and of the cases who were, only half presented to hospital.

Pulse oximetry can identify child pneumonia patients at high risk of death independently of clinical IMCI criteria[6 7] and is a critical part of oxygen services in reducing child pneumonia mortality.[17] Our study team has identified potential structural obstacles preventing high uptake of pulse oximetry in the Lagos setting, including economic disincentives (eg, facilities can charge for laboratory diagnostics but were not charging for pulse oximetry), workforce 'brain drain' and staff shortages (eg, active recruitment of HCWs to other countries at the same time as hiring freezes) and general low HCW motivation post-pandemic (eg, feelings of underappreciation and overwork).[18] It is possible that the intervention was too narrowly focused on pulse oximetry and oxygen—especially as we focused on pneumonia patients only, without addressing broader challenges with triage, stabilisation and referral.[2] While IMCI offers an integrated approach to primary care provision, our stabilisation room intervention may have benefited from an additional focus on Emergency Triage and Treatment (ETAT).[19] Work in other settings suggests that expanding ETAT, which was designed for hospital settings, to primary care is feasible but that similar health systems barriers would likely persist.[20–22]

We observed important differences in oxygen treatment for hypoxaemic patients by facility type, with a significant increase for government PHCs only (from 1% during the baseline period to 20% in the implementation period). The change in those who were also referred and admitted however was more muted. Therefore, despite finding an improvement in oxygen treatment, short-term oxygen delivery in an outpatient setting may not be desirable if it demotivates HCWs referring to and patients from seeking care at higher level facilities. Indeed, half of hypoxaemic cases treated with oxygen in government PHC in the implementation period were treated in the stabilisation rooms, and not in hospitals. Our intention was that the stabilisation room package would lead to children being put on oxygen while arranging transportation, and then on subsequent admission to hospital. It is therefore unclear if our findings show a treatment success (ie, short-term stabilisation was sufficient) or failure (ie, shorter oxygen treatment was deemed an adequate replacement for hospital care). While it is possible that for some hypoxaemic cases, short-term oxygen treatment was enough, or that some cases did not have sustained hypoxaemia (eg, due to poor perfusion initially causing spurious measurement, subsequently resolved with intravenous fluids), it remains that IMCI policy is to refer all hypoxaemic children, either with or without stabilisation first. Given referrals present a major challenge in many settings,[4 23] careful consideration needs to be given to the potential unintended consequences of providing paediatric oxygen care in PHC settings which are not designed for longer-term care.

Oxygen treatment of hypoxaemic cases who presented to outpatient departments of secondary facilities was expectedly higher, but did not change from baseline (46%) to implementation (40%) periods, suggesting the adoption of oximetry was the limiting factor. Previous research from secondary facilities in Nigeria, where pulse oximetry adoption improved, identified key success factors which we may have been lacking. For example, senior staff that lead by example and take on the role of reminding, encouraging and demonstrating pulse oximetry use was highlighted as important.[24] It has been shown repeatedly that training alone has limited efficacy in improving quality of care[25]; it is likely that the lack of planned supervision and mentorship affected impact.

We found no difference in our secondary outcome, the CFR: during the baseline period the CFR was 0.8% and during the implementation period it was 1.2% (p=0.299, table 2). This is likely due to most of the hypoxaemic cases still remaining untreated with oxygen in the implementation period, indeed of the 14 deaths in the implementation period, 8 were hypoxaemic and none of these were treated with oxygen (online supplemental figure 1h) Oxygen is life-saving, with a recent systematic review and meta-analysis estimating a treatment effect on childhood pneumonia mortality of an OR of 0.52,[26] and if it were used in these cases we therefore expect around half of them to have survived.

Correct diagnosis of pneumonia was very low throughout (7.8% in the baseline period and 11.2% in the implementation period), with only 31% of pneumonia cases diagnosed as an acute respiratory infection, pneumonia or severe pneumonia by health workers. This likely contributed to the lack of improvement in our primary outcome, correct management of hypoxaemic pneumonia cases, as it limited which cases were recognised to be pneumonia in the first place. Misdiagnosis of pneumonia with other common infections, such as malaria and sepsis, is commonly seen,[27] and therefore not necessarily surprising. However, correct treatment of pneumonia cases—that is, with oral antibiotics, which were diagnosed by HCWs as coughs, malaria or other diagnoses, was worrying. Many of the cases were presumptively treated with antibiotics when they should not have been according to the HCW diagnosis. Given the increase

in correct treatment of HCW diagnosed pneumonia cases was lower than that for other diagnoses there was limited improvement in pneumonia case management.

The proportion of pneumonia cases that were diagnosed with danger signs by our clinical data collectors was high, and a lot higher in the baseline period (59%) than the implementation period (20%). This was true for all danger signs (see notes to table 2), so is unlikely to be solely due to a misunderstanding or change in understanding by our clinical data collectors. One explanation may be both direct and indirect effects of COVID-19, with the acute stage of the pandemic overlapping with the baseline period. Lagos was the epicentre of the Nigerian COVID-19 outbreak,[28] and children may have been presenting with SARS-CoV-2 infections. Data from other settings demonstrated abnormal seasonal circulation of respiratory pathogens (such as RSV) in this time period,[29] and a lack of testing and laboratory data precludes us from knowing whether the cases in our study had SARS-Cov-2 infection or infection by other seasonal pathogens. This may also explain our finding of a higher proportion of pneumonia cases being hypoxaemic in the baseline period (13.9%) than the implementation period (5.2%). Indirect impacts of the pandemic in this setting included alternative and delayed care-seeking for children.[30] It is possible this delayed care seeking resulted in children presenting in primary care with more severe illness.

The main strengths of our study were the prospective nature of 26 months, and use of trained clinical data collectors to record pneumonia cases and hypoxaemic pneumonia cases, to compare HCW diagnosis to. We also included a mix of facility types in our 16 health facilities, including private facilities. The fact we did not find many hypoxaemic pneumonia cases in the seven private facilities is an important finding for targeting future investments.

Our study also has three key limitations. First, although part of our protocol,[11] we only recorded a single confirmed COVID-19 case. This is likely due to stigma, uncertainty and fear surrounding COVID-19,[30] as well as limited COVID-19 testing capacity and uptake in Lagos.[30] Second, our clinical data collectors were considered as the reference standard, but they may not have perfectly identified pneumonia cases and as such are not a true gold standard for comparison. Our clinical data collectors were trained and re-trained and supervised throughout the study, and we did not find major differences between our 21 clinical data collectors, though numbers were small for most outcomes. Finally, our target population was children with clinical pneumonia, and this may have limited our assessment of impact. Given hypoxaemia is common in other childhood conditions in Nigeria,[31] identification and management of non-pneumonia hypoxaemia may have changed as a result of the INSPIRING programme.

Our findings raise important questions about the role of primary care in managing paediatric hypoxaemia, with barriers to adequate clinical care for children with pneumonia in Lagos remaining. It is clear that equipment and training alone are insufficient, and there is an urgent need for implementation research which focuses on systems challenges and solutions. Although our study did find a small improvement in treatment of hypoxaemic paediatric pneumonia cases following the introduction of a programme of pulse oximetry and oxygen provision and training, there is a long way to go. A key component of the planned intervention—ongoing supervision and mentorship, was not completed as planned and understanding both the impact of this and implementation barriers is needed. Our concurrent mixed-methods process evaluation explores HCW perceptions of pulse oximetry and oxygen and their perceived role, as well as trying to unpick the broader facility-level social and physical barriers to using pulse oximetry and oxygen.[16]

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group) concerning the legal status of any country, territory, jurisdiction or area or of its authorities. This map is provided without any warranty of any kind, either express or implied.

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