

Understanding health innovation adoption: a realist evaluation of pulse oximeter implementation in primary care for children under 5 in four West African countries

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To cite: Louart S, Balde H, Coulibaly A, *et al*. Understanding health innovation adoption: a realist evaluation of pulse oximeter implementation in primary care for children under 5 in four West African countries. *BMJ Glob Health* 2025;**10**:e017303. doi:10.1136/bmjgh-2024-017303

Handling editor Emma Veitch

► Additional supplemental material is published online only. To view, please visit the journal online (<https://doi.org/10.1136/bmjgh-2024-017303>).

Received 27 January 2025
Accepted 30 October 2025



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ABSTRACT

Introduction Hypoxaemia is an important contributor to child mortality, particularly in low-resource settings where diagnostic tools are scarce. The Améliorer l'Identification des détresses Respiratoires chez l'Enfant project introduced pulse oximeters (POs) into 202 primary healthcare centres (PHCs) in Burkina Faso, Guinea, Mali and Niger, integrating them into the Integrated Management of Childhood Illness guidelines. This initiative aimed to strengthen diagnostic capacities for identifying hypoxaemia and to improve care management for critically ill children under 5. This study examined how healthcare workers (HCWs) adopted POs and explored the contexts and mechanisms influencing their adoption.

Methods We conducted a realist evaluation to analyse adoption patterns, focusing on interactions between the Intervention, Contexts, Actors, Mechanisms and Outcomes (ICAMO configurations). Data collection included 299 interviews with HCWs, patients' families and institutional actors, conducted in 16 selected PHCs, at the institutional level and in district hospitals, complemented by site observations. Analysis was performed using NVivo software, identifying ICAMO configurations as semi-regularities to explain variations in PO use and adoption.

Results Training enabled HCWs to recognise the utility of POs, further motivating their use. Support-focused supervision fostered a sense of support, while control-focused approaches sometimes resulted in mechanical use driven by external pressure. In contexts of high workloads and children's agitation, difficulties in using POs were observed. In settings with limited diagnostic tools, POs increased HCWs' diagnostic confidence, encouraging adoption and improving decision-making. Observing or knowing the benefits of POs on children's health provided HCWs with a sense of relief and pride, further reinforcing PO adoption. However, structural barriers and challenges related to institutional adoption may threaten long-term use.

Conclusions This study sheds light on the contexts and mechanisms that influence the use and adoption of

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Severe hypoxaemia significantly contributes to child mortality, especially in low-resource settings lacking adequate diagnostic tools.
- ⇒ Pulse oximeters (POs) are effective in detecting hypoxaemia and guiding referrals, particularly when integrated into the Integrated Management of Childhood Illness guidelines.

WHAT THIS STUDY ADDS

- ⇒ Using a realist evaluation approach, this study identified diverse responses to PO implementation, explaining the reasons for non-use, mechanical use, use and adoption. POs appear to be predominantly adopted at an individual level.
- ⇒ Findings highlight the critical role of boosting confidence in healthcare providers' diagnostics, as well as the sense of relief and pride derived from participating in the care of children, to support adoption.
- ⇒ Structural and institutional challenges, including training, supply chain issues, device maintenance and referral system inadequacies, were found to potentially hinder the sustainability of PO adoption.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ The study provides valuable insights into the contexts and mechanisms that facilitate or hinder the adoption of POs, which may also inform the integration of other diagnostic tools into primary healthcare systems.
- ⇒ Policy-makers and healthcare implementers can use these findings to design tailored strategies to implement similar interventions in other contexts.

the PO in PHCs. While widely used by HCWs, addressing challenges related to training, supply chain logistics and referral systems to hospitals is essential to ensure long-term sustainability and improve child health outcomes.

INTRODUCTION

Infectious diseases, particularly respiratory infections, are leading causes of child mortality,^{1 2} especially in sub-Saharan Africa, where socioeconomic factors such as poverty and inadequate home ventilation contribute to their high prevalence.³ West Africa has the highest child mortality rates under 5, largely due to infectious diseases. However, efforts and resources to address this public health issue remain insufficient.⁴

Severe hypoxaemia, defined as a blood oxygen concentration below 90%, is a key indicator of the severity of acute lower respiratory tract infections⁵ but also a marker of severity for other common conditions like malaria and malnutrition.⁶ In low-income and middle-income countries, hospital studies report significant prevalence rates of hypoxaemia, varying according to age, disease type and illness severity.^{7–9} This severe hypoxaemia substantially increases the risk of death in children.⁵ However, clinical symptoms alone are insufficient to reliably detect hypoxaemia, underscoring the interest of devices that measure oxygen saturation for identifying children requiring urgent care,^{10 11} including oxygen therapy.^{12 13} International calls have long advocated for improved access to oxygen and diagnostic tools like pulse oximeters (POs),¹³ which measure oxygen saturation and help detect hypoxemia cases.

To enhance child healthcare, the WHO introduced the Integrated Management of Childhood Illness (IMCI) strategy in the 1990s, aiming to prevent and treat severe childhood illnesses in low-resource settings.¹⁴ In 2014, the IMCI clinical guidelines were updated to include specific recommendations for respiratory diseases, advocating for the use of PO 'when available' and the transfer to facilities equipped to administer oxygen when oxygen saturation falls below 90%.¹⁵ However, access to PO and oxygen in low-income countries remains inadequate,¹⁶ especially in primary care settings,¹⁷ limiting the potential impact of this recommendation.

Although studies have demonstrated the effectiveness of PO for identifying critical cases that could go unnoticed with IMCI alone,^{18 19} evidence on its impact at the decentralised level remains scarce. A study in Uganda is one of the few to examine this aspect.²⁰ Furthermore, there is a significant gap in qualitative research exploring the processes of PO implementation and adoption, particularly in decentralised primary care settings.²¹ Recently, a realist evaluation in Nigeria provided valuable insights, revealing that PO adoption in these settings was both limited and uneven.²²

To tackle these challenges, the AIRE project (Améliorer l'Identification des détresses Respiratoires chez l'Enfant) was implemented in four West African countries: Burkina Faso, Guinea, Mali and Niger. Led by a consortium of non-governmental organisations (NGOs), this project aimed to strengthen diagnostic capacities for severe hypoxaemic cases at the primary care level by introducing the routine use of PO during IMCI consultations. A multifaceted study was conducted to understand the

introduction of PO in these settings.²³ A key element in disseminating innovations is understanding the factors influencing their adoption (or non-adoption).²⁴ Given the complexity of implementing innovations in primary healthcare centres (PHCs), a realist approach²⁵ was used to explore the contexts and mechanisms that facilitate or hinder the adoption of PO by healthcare workers (HCWs). This study sought to answer the overarching question: how does the AIRE project work (or not), for whom, in which specific contexts, and why? It further explored how HCWs responded to the intervention, which contextual elements shaped these responses, and what effects these responses produced on the use and adoption of PO.

METHODS

To ensure transparency and completeness in reporting, we followed the Consolidated Criteria for Reporting Qualitative Research checklist when writing this section.²⁶

Research team and reflexivity

In each country, data collection was coordinated by a researcher trained in socio-anthropology, specialised in qualitative research, and with substantial experience in public health research (HB, AC, AED and KK). This person recruited data collectors to conduct the qualitative interviews. Interviewers were chosen based on their postgraduate degree in socioanthropology, their familiarity with the sociocultural context and their ability to speak the most widely used languages in the study areas. The research teams included both male and female interviewers. None were affiliated with the national health system or with the implementing NGOs; all were selected to ensure independence from the intervention. No prior relationship existed between interviewers and participants. They were informed that the interviewers were independent from the implementation team and that the purpose of the study was to better understand the use of the PO in routine care settings.

Intervention and research sites

The AIRE intervention was implemented from July 2019 to December 2022 in two health districts within each of the four countries: Burkina Faso, Guinea, Mali and Niger (figure 1), encompassing 202 PHCs and 8 district hospitals. The IMCI guidelines were primarily used in paper format, except in Burkina Faso and one district in Mali, where electronic IMCI was employed as part of the Integrated e-Diagnostic Approach programme.²⁷ Project activities included training in PO use and refreshing HCWs in IMCI, distributing POs, conducting supervision visits and strengthening care capacities at PHCs (basic medicines and medical equipment) and district hospitals (POs and oxygen concentrators).

The research was conducted primarily in 16 selected PHCs (four per country), designated as sites 1–4 in each country. Additional investigations occurred at hospital and institutional levels, including district teams and

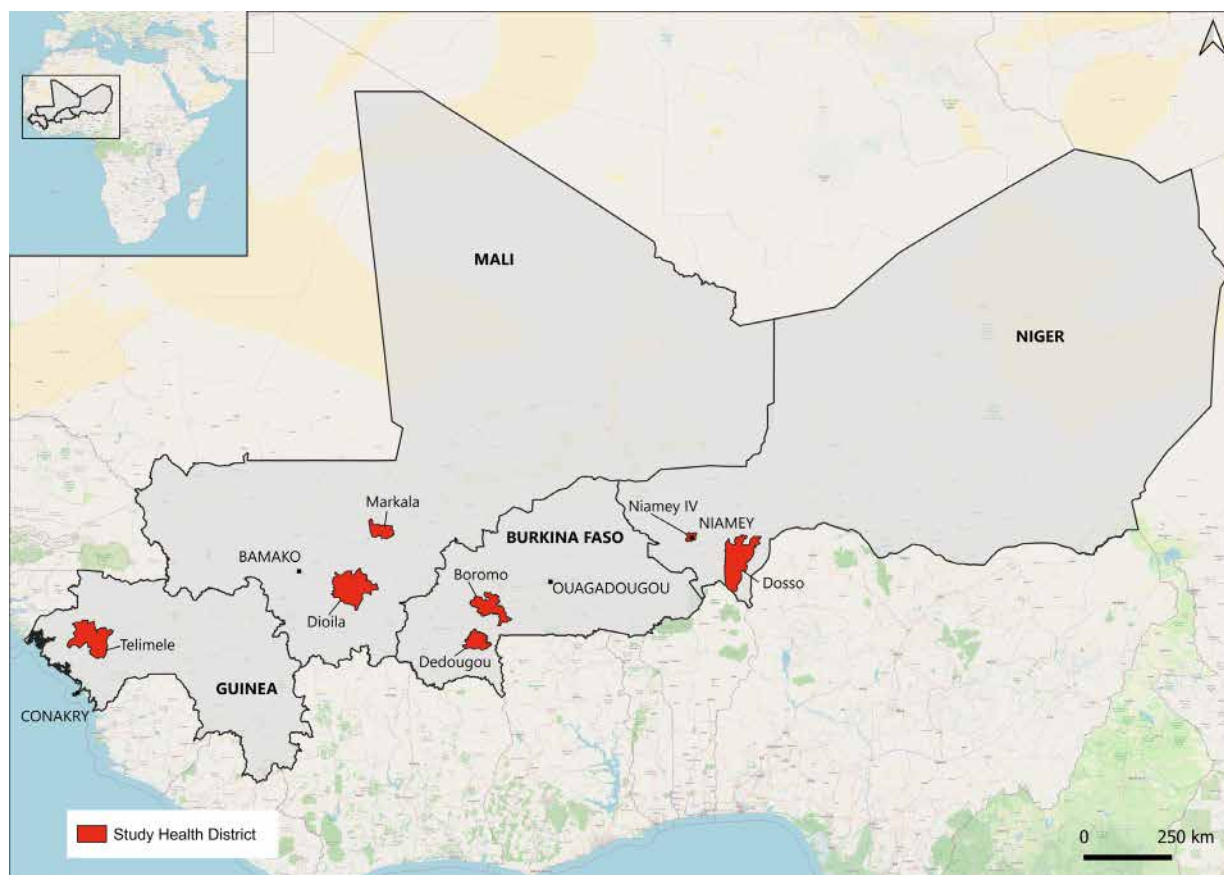


Figure 1 Countries and health districts involved in the AIRE study. AIRE, Améliorer l'Identification des détresses Respiratoires chez l'Enfant.

ministries. Details on the intervention, research site selection criteria and eligibility criteria for children's PO use are outlined in the study protocol.²³ Characteristics of the sites are described elsewhere.²⁸

Study design

We conducted a realist evaluation²⁵ to gain an in-depth understanding of HCWs' adoption or non-adoption of PO. This approach seeks to understand how and why an intervention produces specific outcomes by exploring underlying mechanisms—namely, the reasoning and reactions of individuals in response to resources provided by the intervention.²⁹ These mechanisms are triggered only in specific contexts, requiring an analysis of the dynamic interactions between context, mechanisms and observed outcomes. To model this dynamic, realist evaluation employs Context-Mechanism-Outcome (CMO) configurations as a heuristic tool, facilitating the development of analytical and robust explanations of results. We began by formulating our hypotheses using Intervention-Context-Actor-Mechanism-Outcome configurations to specify the intervention and target actors of our study (PHC HCWs).³⁰ As we moved towards a higher level of abstraction, we employed CMO configurations to develop the middle-range theory (MRT).

The evaluation begins with reconstructing the programme theory, that is, the underlying assumptions

about how an intervention is intended to work and the impacts it is expected to have.³¹ These initial assumptions are gradually refined, aiming to develop an MRT.³² Realist evaluation thus favours theoretical generalisation,³³ supporting the formulation of practical and contextualised recommendations for policymakers by progressively refining the programme's initial theory.

Our realist evaluation design is illustrated in figure 2. We organised three research workshops that brought together the research team responsible for conducting the realist evaluation and members of the project coordination team. These workshops supported collaborative work on key stages of the realist evaluation process. The first framed the research and refined the initial intervention model through discussions with coordination teams at both country and international levels, while the second and third focused on adjusting and refining hypotheses, leading to the formulation of 26 theoretical hypotheses. These hypotheses were developed based on preliminary field data, scientific literature—including realist studies on PO use in Nigerian hospitals,³⁴ a realist review on access to oxygen and extensive literature on innovation adoption.^{35–37} The process of refining the programme theory is detailed in online supplemental appendix 1.

This article follows the guidelines Realist And Meta-narrative Evidence Syntheses: Evolving Standards for

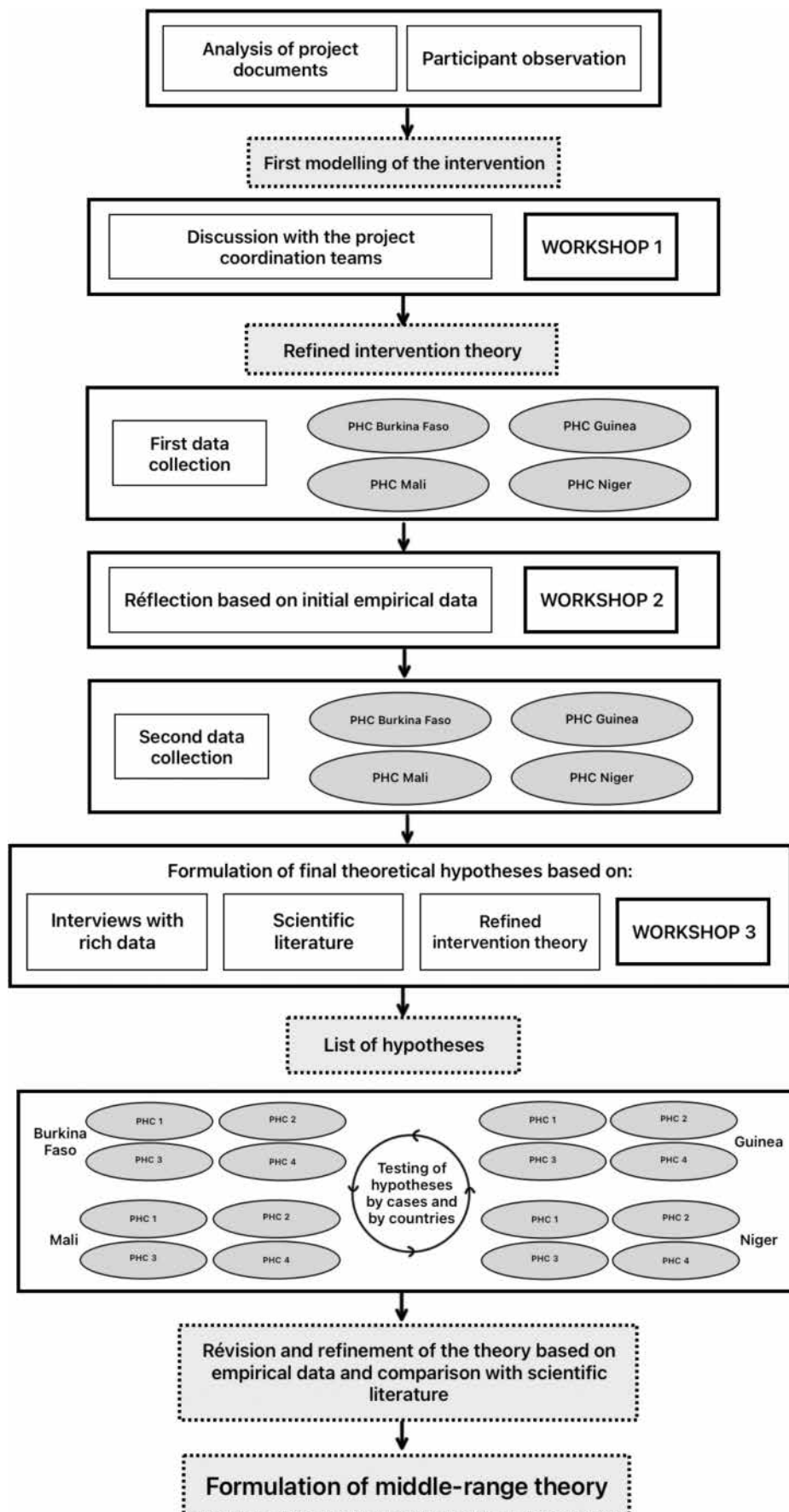


Figure 2 Realist evaluation design of the AIRE Project. AIRE, Améliorer l'Identification des détreesses Respiratoires chez l'Enfant; PHC, primary healthcare.

reporting realist evaluations to ensure transparency and rigour.³⁸

Data collection

We conducted two rounds of data collection. The first (T1) occurred in November and December 2021, approximately 6 months after the introduction of the PO in the PHCs. The second (T2) took place in October and November 2022, at the end of the project's main activities. In Mali, Guinea and Burkina Faso, two data collectors were involved, whereas in Niger, one person conducted all the interviews. Each national team was trained by the country research supervisor, who had previously received common project-level training during a research workshop held in Dakar.

Interviews were conducted in French or in local languages, depending on the participants' preferences. All interviews with HCWs took place in private spaces within PHC, such as unused consultation rooms or offices. For families of children, interviews were conducted either near the PHC or in the villages, based on participants' availability and preferences. Participants were invited to take part in the study once their consultation was over. It was clearly explained that their participation would have no impact on the care they or their children would receive, and that all information shared would remain confidential. No other people were present during the interviews.

A standardised semistructured interview guide was used across all countries. It was developed in French and translated into local languages where necessary. The guide allowed for open-ended responses and flexible probing. Interviews were audio-recorded with participants' consent, and transcripts were produced by the national research teams. When needed, interviews were translated into French, and when translation issues arose, or local expressions were highly context-specific, certain terms were retained in both languages. National research coordinators reviewed the transcripts for accuracy. Due to logistical constraints and participants' limited availability, transcripts were not returned to participants for validation. Interviews lasted between 30 min and 1.5 hours. No repeat interviews were conducted, and no participants declined or dropped out.

In both phases, we used exhaustive sampling for HCWs consulting children under 5 at PHCs and available during the survey. For other groups, including families of the children, HCWs at district hospitals and individuals involved in project monitoring at the institutional level, we used purposive sampling.²³ Observations were also carried out in PHCs, including clinical consultations with the PO.

Data analysis

The interviews conducted with HCWs in PHCs served as the primary data source for this study. Additional interviews with other participants, field notes and observation reports were used to triangulate the data. Each source

offered a partial and situated perspective on the phenomenon under study; their cross-analysis made it possible to identify convergences (mutual reinforcement of narratives), reveal contradictions (highlighting tensions or blind spots) and better contextualise the observed practices and representations—thus reinforcing the depth and robustness of the realist analysis. The data from interviews with families are presented in detail in a separate article.³⁹

Our analysis focused on identifying four main outcomes of the intervention: use, non-use, unsustainable use (which can be described as mechanical, circumstantial, temporary or compliance-driven use), and adoption of the PO. Use refers to any application of the PO that reflects at least some level of engagement or recognition of its value, whether systematic or occasional, and may constitute a first step towards adoption. Use is considered necessary for adoption, as specific configurations associated with it can generate feedback loops that ultimately support sustained use. Mechanical use, by contrast, refers to use performed under obligation or automatically, without genuine appropriation, for instance, merely to fill out forms or report data. These forms of usage are dynamic: mechanical use can sometimes evolve into voluntary use when HCWs come to appreciate the tool's relevance and integrate it into their daily practice. Adoption implies a voluntary and sustained integration of the PO into HCWs' practices.

Data analysis followed an iterative process guided by realist methodology. Coding was conducted using a codebook developed from the initial list of hypotheses formulated during the construction of the intervention theory. These hypotheses were examined and progressively refined based on emerging findings from the interviews. To ensure rigour and reliability, double coding was conducted using NVivo V.12: initial coding was performed by the research coordinators in each of the four countries, and a second round was carried out by the international research coordinator. An approach by case studies was adopted, with cases selected for their distinct characteristics to guide data collection. Comparisons were then conducted within and across cases to identify patterns, refine interpretations and strengthen the analysis.³³ The final list of hypotheses was revised by integrating empirical findings with the existing literature, ultimately contributing to the development of an MRT. Participants did not provide feedback on the findings, and the results were not returned to them for validation.²²

Patient and public involvement

Data collection was authorised by ethics committees and ministries of health. The study participants were not directly involved in the analysis, interpretation of results or manuscript preparation. However, key findings were shared during dissemination sessions with HCWs, health authorities and public representatives to support collective interpretation and inform practice.

Table 1 Distribution of interviews by data collection period, respondent groups and country (N=299)

Data collection period	Respondents	Countries				Total
		Burkina Faso	Guinea	Mali	Niger	
T1	HCWs at PHCs	11	11	12	13	47
	Other PHC staff	3	8	12	11	34
	Community health workers	7	8	8	8	31
	Families of children	16	16	16	11	59
Total T1=171 interviews						
T2	HCWs at PHCs	13	11	12	17	53
	Hospital health workers	20	5	17	9	51
	Institutional level	3	6	6	9	24
Total T2=128 interviews						
Overall total=299 interviews conducted						
HCWs, healthcare workers; PHCs, primary healthcare centres.						

RESULTS

During the two rounds of data collection, 299 interviews were conducted with various target populations. [Table 1](#) presents the distribution by timeframe and country. [Table 2](#) presents the different configurations of our MRT, developed based on the demi-regularities identified in the data, supported by selected examples of citations. Additional illustrative quotations are provided in online supplemental appendix 2.

We present the main configurations identified in the data, outlining the key contexts, mechanisms and outcomes that explain the use and adoption of PO in PHC settings. These results are summarised in [figure 3](#).

PO use

First, in these settings, diagnostic technologies are typically reserved for higher levels of care and high-status professionals, such as doctors. In this context of medical hierarchy and resource scarcity, shared across the four countries studied, introducing the PO at the primary care level was thus perceived as a source of pride, enhancing HCWs' sense of legitimacy in providing care. This perception was reinforced, particularly in Burkina Faso and Mali, by the sense of privilege associated with having the PO in selected centres, especially since other PHCs in the country did not receive the device.

Additionally, being part of a pilot project added pressure and motivation for HCWs to use the PO, as its potential scaling partly depended on the data collected in these research PHCs. This dynamic was particularly salient in Burkina Faso and Mali, where participation in the project fostered both a sense of pride and a responsibility to meet expectations and deliver positive outcomes. Some HCWs emphasised the need 'to set an example' (Burkina Faso, T2, PHC2) or 'not to disappoint' (Niger, T1, PHC3) project members.

This feeling of pride was also reinforced by HCWs' perception of increased family trust and higher attendance at PHCs. In areas where PHCs often lack

diagnostic tools, the PO enhanced the centre's image, attracting more patients and strengthening trust as families appreciated the introduction of this new technology. This perception was particularly emphasised in Mali, where HCWs highlighted that increased attendance also contributed to improving the financial resources of the PHC. It was further confirmed by interviews with families, who expressed greater confidence in the care provided. As HCWs noted, 'the quality of the consultation is there, and it attracts patients' (Guinea, T1, PHC3) and 'the PO is a tool that has created more trust between us and the patients' (Mali, T1, PHC1).

Training sessions also played a key role in promoting PO use by raising awareness of its practical benefits. This effect became particularly evident during the second round of data collection, as the progressive training sessions conducted through the AIRE project enabled an increasing number of HCWs to recognise the value of the PO in their practice. Training sessions not only enhanced HCWs' understanding of the PO's value in refining diagnoses and detecting emergency situations related to hypoxaemia, but also emphasised its role in facilitating referrals to hospitals where children could access oxygen therapy.

Support-focused supervision, offering encouragement and guidance, also motivated voluntary PO use. This approach helped HCWs feel supported and reinforced their understanding of the project's importance. This support came from various sources. In some cases, the presence of clinical investigators was positively received. When supervision by the project and district teams was inclusive—involving all staff members rather than focusing solely on PHC managers—it also further promoted PO use. Positive support from PHC managers was also highlighted by several HCWs. Managers who actively used the PO themselves were perceived as setting an example and 'showing its importance to others' (Burkina Faso, T1, PHC3). This visible leadership

Table 2 Configurations of the middle-range theory

When the PO is introduced at the decentralised level, where technology is scarce, and in selected centres—as the project was implemented in specific districts rather than nationwide, with only some centres within these districts selected for the research (C), HCWs experience a sense of pride (M), a feeling of luck (M), an enhanced sense of legitimacy (M) and a pressure to meet expectations (M), which encourages them to use it (O).	“When I use it, I feel like I’ve become more legitimate, like I’ve become a doctor, because before, it was the doctor’s job. You only see it in intensive care units. (...) Now, we feel proud. (...) The introduction of the PO has turned us into doctors” (Niger, T1, PHC 4) “Since we’re a study site, that already makes a difference from other health sites (...) we’re held to good practices to make sure it goes well. (...) Being told that our site would be a study site was stressful. (...) For the health centre, it’s a privilege for us to be part of the study. (...) If the research is successful, it’s a national pride, not just regional for the district.” (Burkina Faso, T1, PHC 2)
When HCWs are trained in the use of PO (C), they become aware of its utility and potential benefits (M), which motivates them to use it (O).	“Since the training, we have seen that it’s very important, because before we didn’t have a device that could really tell us if a child was in respiratory distress or not. We were treating them, I could say, ‘blindly’. But after the training, we saw the importance of the PO, really, it’s something very good.” (Guinea, T1, PHC 1)
When regular oversight is imposed on HCWs (C), they feel obligated to use the technology to meet expectations and avoid reprimands (M). This compelled use is often mechanical and driven by external pressure rather than a genuine belief in the tool’s benefits, which may jeopardise sustainable use of PO (O). This obligation may also arise in contexts where usage is mandated by the digitisation of IMCI.	“At the very beginning, people weren’t interested in the tool. But now, such cases are rare. At first, when you examine a child and refer them to the AIRE investigator, the investigator will ask the mother if the healthcare worker used something on the child’s finger. If the mother says no, the investigator will personally get up, go with the mother, and confront you, saying the mother mentioned you didn’t use the PO. I know this happened once or twice with a healthcare worker at the PHC here. Since that day, no mother comes with her child without the PO being used.” (Burkina Faso, T2, PHC 1) “During supervisions, they check the registers and all the records... When we measure saturation, we’re required to document it, and as soon as a supervision visit takes place, it’s obvious they’ll review the register to see if the PO is being used.” (Niger, T2, PHC 1)
When HCWs are actively and positively supported in their use of the PO, through regular guidance or encouragement that highlights its value (C), they feel supported (M) and recognise its relevance and usefulness (M). This motivates them to integrate the PO into their activities, thereby promoting a more voluntary use of the tool (O).	“Supervision comes to galvanize us. Supervision is like moral support, an accompaniment. It encourages us to use the PO.” (Burkina Faso, T2, PHC 1) “That’s what tells us the device is truly useful. They encourage us, they come to check, they supervise us.” (Niger, T2, PHC 4).
In contexts where patient management is complicated and the workload is perceived as high (C), HCWs perceive the use of PO as an additional burden (M), leading to reluctance to use it optimally or, in some cases, rendering its use impossible (O).	“Care slows down significantly, especially when we’re tired, and particularly here at (PHC 1), where patients only come at night. You’re exhausted, you’ve been working since morning until 6 or 7 p.m. (...) You’re tired, you want to prepare yourself, pray, wash, and they bring you children. And you absolutely have to use the PO... Honestly, you can see there’s a bit of an overload... Yeah, it’s overwhelming.” (Niger, T1, PHC 1) “It’s impossible to use it on certain children because once the child starts crying, all the numbers the PO gives will be inaccurate. (...) There are some children who categorically refuse to have the cable attached to their toe or finger. (...) If I encounter this type of child every time during consultation, it can lead to discouragement.” (Mali, T1, PHC 1)
In contexts where HCWs face challenges in making diagnoses due to material limitations (C), the use of PO enhances their confidence in themselves and their ability to make accurate diagnoses (M), encouraging its adoption (O).	“Previously, we struggled with children here, doing things blindly because we had no way of truly knowing what their problem was. (...) I use the PO to feel good, to be confident in the outcome of the consultation. I do it to spare myself any doubt about the oxygen level in a child’s blood. The PO gives me something concrete and allows me to feel at ease and confident.” (Mali, T2, PHC 4)
When HCWs are informed about the benefits of this technology or have observed its positive impact on patients’ health directly (C), it provides them with a sense of relief and pride (M), which further supports PO adoption (O).	“We guide the children until they reach a place where they can receive care. Some come back and say, ‘Doctor, we’re grateful to you. Thankfully, you referred us to that place.’ We experience this often. When we tell them to go, some say, ‘Ah, we’re just going’ but once they leave, they recover and come back joyful. (...) We have seen the importance of the PO; we have seen the downside of not using it. (...) When we use it with a child who is lacking oxygen and we refer them, if they recover, we feel proud.” (Guinea, T2, PHC 2)
C, context; HCW, healthcare worker; IMCI, Integrated Management of Childhood Illness; M, mechanism; O, outcome; PO, pulse oximeter; T1, first round of data collection; T2, second round of data collection.	

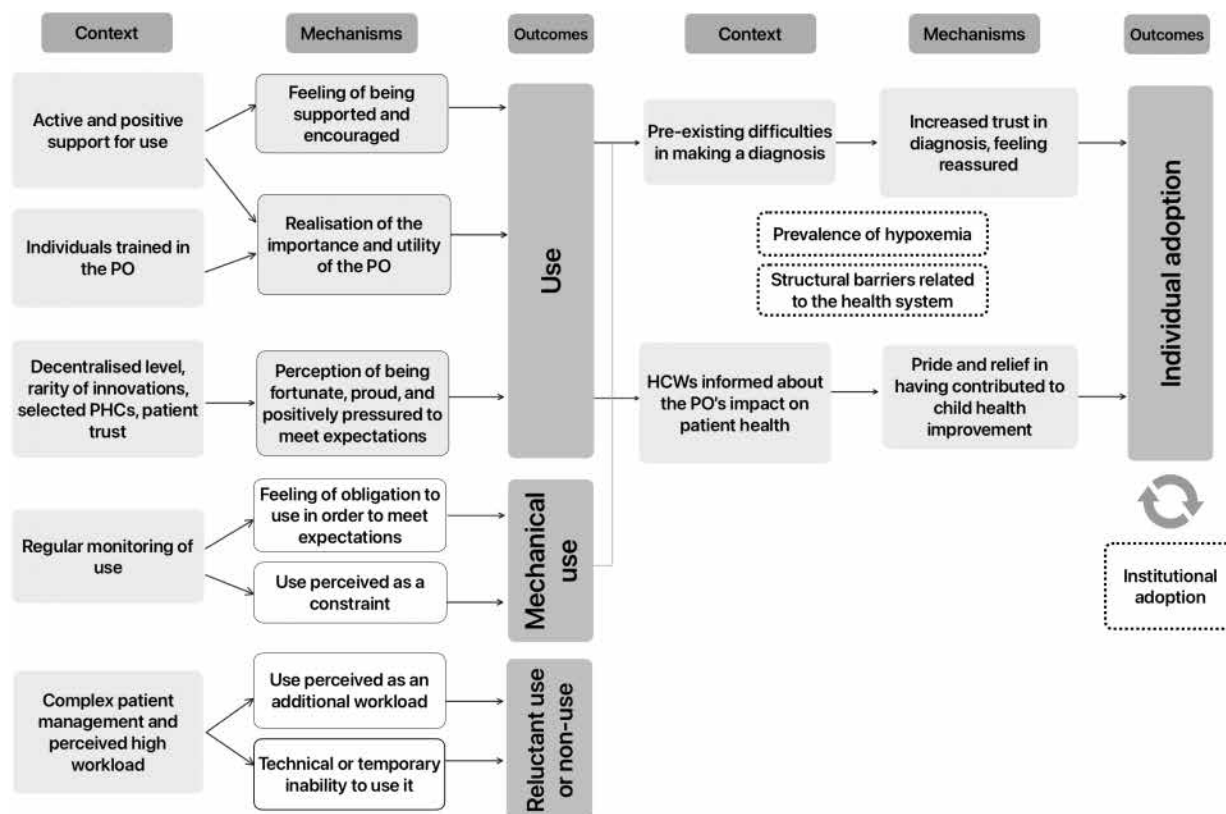


Figure 3 Middle-range theory of PO adoption. HCWs, healthcare workers; PHC, primary healthcare; PO, pulse oximeter.

encouraged other HCWs to view the PO as an essential tool, reinforcing their commitment to use it.

PO mechanical use

In contrast, control-focused supervision emphasised performance monitoring and compliance generating pressure rather than support. Clinical investigators, employed by the project and present daily in the PHCs for over a year, had a significant influence on PO use, particularly in Burkina Faso and Guinea. Tasked with collecting clinical data, they actively urged HCWs to use the PO by checking consultation registers, insisting on its systematic use and reminding those who did not comply. As one HCW explained: “they put a lot of pressure on us” (Guinea, T1, PHC2).

Similar pressure was sometimes exerted by PHC managers through record checks, consultation monitoring or reminders of their professional responsibilities. While such practices were not reported in Guinea, they were mentioned in the other countries. In Niger, for instance, one HCW noted: “I assure you that she [PHC manager] monitors strictly! So, no one wants to be the source of any issues!” (Niger, T2, PHC3).

Supervision from project or district teams was also sometimes perceived as controlling, especially during the second round of data collection and in Burkina Faso. However, perceptions of supervision varied depending on how it was implemented. When supervisors focused more on outcomes than support, HCWs tended to anticipate

oversight with apprehension, taking measures to avoid exposing errors or non-compliance.

Finally, the digitisation of IMCI protocols—used mainly in Burkina Faso, where it was implemented in both study districts, and to a lesser extent in Mali—contributed to reinforcing PO use. The electronic consultation register required that oxygen saturation be entered before a diagnosis could be validated, effectively compelling HCWs to use the PO.

Challenges in using the PO

We also identified contexts that may hinder PO use. Children’s agitation during consultations emerged as the primary reason for non-use, particularly during the first phase of data collection. This agitation not only prolonged the time required to use the device but, in some cases, made its use entirely impossible. Observations conducted in PHCs confirmed these challenges, as HCWs were sometimes seen struggling to obtain readings on agitated children. Often linked to a general fear of healthcare facilities or the use of the malaria Rapid Diagnostic Test (mRDT) requiring a puncture, this issue prompted HCWs to adapt their practices. For example, some HCWs used the PO at the beginning of the consultation (before the mRDT) and employed various strategies to calm children and demonstrate that the device is painless.

Another barrier to PO use was the increased workload, particularly reported in Burkina Faso. This burden was

especially evident in high-volume settings with limited staff, making PO use challenging due to time constraints, particularly during peak periods or when dealing with impatient patients. To alleviate this burden, some PHCs implemented strategies such as separating adult and child consultations, using the PO during triage, or conducting paediatric consultations with two HCWs. However, the feasibility of these solutions remained dependent on sufficient human resources.

PO adoption

Two configurations were identified as pathways to adoption. Before the introduction of the PO, the limited availability of diagnostic tools in PHCs meant that HCWs mainly relied on clinical examination, which made decision-making uncertain and stressful. Many HCWs described challenges in making accurate diagnoses: “Before, we consulted children with uncertainty” (Mali, T1, PHC1). Many reported difficulties in making accurate diagnoses and described situations where they had to decide, based on limited clinical signs, whether to keep a sick child under observation or send them home despite signs of possible deterioration. Introducing the PO reduced this uncertainty, providing HCWs with a greater sense of confidence and calm in their decision-making: “The PO allows me to be sure of what I’m doing and saves lives” (Mali, T2, PHC4).

Adoption was also strengthened by direct or reported observations of the PO’s usefulness in improving child-care, which gave them a sense of relief and motivation to adopt the device in their daily practice. This response was particularly noted in Mali. Although the benefits of the PO were often inferred due to the limited availability of oxygen at the decentralised level, HCWs reported feeling reassured when they received updates about a child’s improved condition, either through caregivers’ feedback or follow-up exchanges with hospital staff.

Structural and institutional barriers to PO adoption

While multiple configurations supported the use and adoption of the PO, interviews also revealed several structural and institutional factors that could undermine these dynamics and hinder long-term adoption.

The ability of HCWs to fully appreciate the benefits of the PO might be constrained by weak referral and oxygen supply systems. Without a functioning care continuum, the diagnostic value of the PO remained limited: “If you don’t have the ability to provide ventilation for the child on-site... the problem is not solved.” (Guinea, institutional actor). These challenges were exacerbated after the end of the AIRE project. In several interviews, HCWs mentioned that the withdrawal of project support—including supervision and follow-up—was seen as a threat to maintaining the use of the PO: “it’s not the same as when the investigators were around.” (Niger, T2, PHC1).

Another potential barrier is the relatively low prevalence of hypoxaemia within the total volume of consultations observed in PHCs compared with hospital settings.

Several HCWs reported rarely detecting hypoxaemia, which over time could reduce their confidence in the diagnostic value and necessity of the PO.

Additionally, the study observed signs of individual adoption, but institutional integration remained weak. Many PHCs showed passivity towards institutionalising the PO, relying instead on NGOs to sustain its integration through continued project support or new initiatives. There were few internal strategies to sustain PO use without ongoing external input. Frequent staff turn-over combined with insufficient training for new recruits further threatened sustainability. In many settings, newly assigned HCWs had not received any training on how to use the PO, weakening the continuity of its use in daily practice. As one institutional actor warned, “In three years, none [of the staff] will be trained to use the PO” (Burkina Faso, institutional actor).

Finally, the lack of systems to repair or replace broken devices emerged as a major barrier to long-term use. In PHCs without technical or financial resources to replace damaged equipment, PO use would simply stop: “the care of the child with the pulse oximeter will stop... and we have no way to bring in a new device” (Niger, institutional actor).

DISCUSSION

This study highlights that individual adoption of the PO in PHCs was relatively high, a trend further supported by quantitative data from the AIRE project, which confirmed high utilisation rates.³⁹ However, the intervention produced four distinct outcomes regarding the use and adoption of the PO. Non-utilisation was primarily observed in high-workload settings and in cases where the device could not be used on agitated children. Mechanical use occurred when external pressures, such as supervision, motivated HCWs to use the device out of obligation or constraint, raising concerns about sustainability. Utilisation was linked with increased awareness of the PO’s usefulness, supportive environments and feelings of pride and privilege in accessing the device. Finally, adoption reflected strengthened diagnostic confidence and a sense of pride and relief from contributing to improved care for children.

Several contextual elements shaped responses to the intervention and influenced PO use. Being trained emerged as central, not only for mastering the tool but, more importantly, for recognising its practical utility. Without multiple waves of training and formative supervision, the use of PO could have been negatively affected. As shown in other studies, limited training risks undermining collective ownership and shared responsibility.⁴⁰ Quantitative data from another AIRE study confirmed that training is strongly associated with PO acceptability.³⁹

The decentralised implementation of the intervention also influenced HCWs’ perceptions. In settings with limited diagnostic tools, the PO was often regarded as a valuable innovation, enhancing confidence in diagnosis

and decision-making. This aligns with findings from a realist study, which highlighted that the scarcity of diagnostic tools can encourage the adoption of new technologies.⁴⁰ Indeed, perceptions of its value varied across settings. In Nigeria, some HCWs questioned whether the PO provided added diagnostic value or simply delayed referrals they already deemed necessary.²² In contrast, studies conducted in settings with limited access to laboratory services and located farther from hospitals emphasised the PO's role in assessment, stabilisation and referrals.^{41 42}

Supervision and external motivation also influenced responses, though the impact varied depending on how supervision was perceived. A realist evaluation in Guatemala distinguished between control-focused supervision, which emphasised pressure to meet targets, and support-focused supervision, which prioritised encouragement and practical guidance.⁴³ Studies have shown that leadership styles and supervisory approaches can significantly influence adoption rates. For example, in Kenya, differences in PO use were partially attributed to variations in leadership styles among senior doctors.⁴⁴ In Nigeria, the absence of external support negatively affected PO adoption rates.²² While our study focused on individual adoption, a study in Mali showed that supervision could enhance individual capacity to adapt practices in response to change, while having a more contrasting effect at the team level in resource-constrained settings.⁴⁵ In our study, the end of AIRE project supervision was often seen as a risk to sustained use, given the lack of established structures for ongoing support.

HCWs' motivations varied depending on whether they were externally driven or internally rooted. Insights from Self-Determination Theory⁴⁶ suggest that autonomous motivation, grounded in personal values, is generally more sustainable than controlled motivation, which depends on external pressures. In this context, HCWs' ownership of the PO was strengthened when key actors—such as supervisors or managers—were perceived as supportive rather than controlling. Supportive interactions encouraged HCWs to see the PO as a tool to improve care, while supervision perceived as imposing constraints sometimes resulted in mechanical use without genuine engagement. Interestingly, mechanical use, initially driven by external reminders, did not necessarily hinder adoption. Over time, reliance on external motivation sometimes transitioned into voluntary adoption, reinforced by repeated positive experiences with the PO. Similar patterns were observed in Nigeria, where constrained use eventually evolved into internalised adoption as HCWs gained familiarity and confidence in the tool.³⁴

Practical and structural constraints also shaped responses to the intervention. Children's agitation during measurements was widely reported as a barrier, consistent with findings from other studies.^{41 47} High

workloads and limited human resources complicated consistent use, reflecting challenges noted in studies on other diagnostic technologies.^{48 49} In Guinea, where the number of consultations was lower during the AIRE project, these challenges were less reported.⁵⁰

The intervention elicited a range of responses among HCWs, influenced by perceptions of the PO as a valuable innovation and by different types of motivation. We have seen that the PO was widely regarded as an important tool in decentralised settings, where diagnostic technologies are often scarce. This perception motivated HCWs, who viewed access to advanced equipment as a privilege and a source of legitimacy. Previous studies have highlighted how the social positioning and roles of HCWs influence their relationship with technology.^{51 52} Abejirinde *et al*⁴⁰ also found that a sense of pride in being selected for a project can facilitate the adoption of innovations. This dynamic was further reinforced by increased patient trust,³⁹ echoing findings from other studies where families' confidence in HCWs improved after the introduction of the PO.^{41 44 53}

The PO also enhanced HCWs' diagnostic confidence, which proved to be a key mechanism promoting adoption. HCWs reported greater certainty in their assessments, leading to faster decision-making. Comparable findings were observed in India,⁵⁴ Malawi and Bangladesh.⁴¹ However, this effect was less pronounced in hospital settings, where HCWs already had access to more diagnostic equipment and training. Within the AIRE project, referral rates for hypoxaemic cases were higher than for other severe cases without hypoxaemia,⁵⁵ suggesting a greater reliance on PO-based diagnostics. Similar trends were noted in Malawi⁴² and India.⁵⁴

Beyond diagnostic confidence, HCWs described feelings of pride and relief when observing the PO's positive effects on patient care, further motivating its adoption. Seeing tangible benefits reinforced their belief in the device's utility, aligning with the concepts of observability³⁵ and result demonstrability.⁵⁶ These concepts emphasise that the ability to observe and measure a tool's impact encourages its adoption. A realist review similarly identified the ability to observe positive outcomes as a key motivator for HCWs to use oxygen.⁵⁷

Finally, our findings also highlight the importance of addressing structural and institutional challenges to ensure the long-term adoption and sustainability of the PO. While improved diagnostics enhanced decision-making, limited access to treatment and the need for emergency hospital referrals for oxygen therapy could demotivate HCWs, diminishing the perceived effectiveness of the PO. Well-documented barriers to hospital referrals—including distance, poor road conditions, lack of transportation and family costs—further restricted access to care.^{58 59} The highest number of referrals during the project

was reported in Niger, likely due to the close proximity of PHCs to hospitals, particularly in the capital.⁵⁰ Additional challenges included supply chain issues, device maintenance and training gaps for newly recruited staff. Concerns about the absence of maintenance systems and replacement devices raised fears of disruptions in patient care, echoing findings from other studies that identified malfunctioning devices and insufficient training as major obstacles to technology adoption.^{41 44 60}

Despite encouraging signs of individual adoption, ensuring the sustainability of the PO requires institutional commitment to overcome these barriers. The NGOs involved in the implementation played a key role in supporting the institutionalisation of the PO beyond the project period. They built on processes already underway in the countries, such as the revision of clinical guidelines, and collaborated with the Ministries of Health to ensure that the PO was integrated into these frameworks, including its inclusion in the updated national IMCI guidelines. The objective was to establish the PO as an essential diagnostic tool, to be used alongside other routine instruments such as thermometers and weighing scales in facilities where it is available. NGOs also advocated for the inclusion of the PO in district-level supervision checklists. However, the long-term sustainability of this integration depends on the continuation of these dynamics at the national level after the project ends, particularly through the ongoing training and supervision of HCWs. This includes formalising its use in clinical protocols, establishing regular training programmes to address staff turnover, developing reliable supply chains for maintenance and securing funding and procurement mechanisms to ensure continued availability of the PO in PHCs. These measures must also support hospital referrals and oxygen therapy delivery. For example, a pilot initiative has been implemented to provide oxygen from the PHC level.⁶¹ Such measures are critical to prevent these challenges from undermining adoption efforts and to support the integration of the PO into health systems effectively. Finally, a rigorous assessment of the actual impact of the PO use at PHC level on patient outcomes remains necessary to inform future policy and scale-up strategies.

This study has some limitations that should be acknowledged. First, contextual and methodological biases may have influenced the findings. Social desirability bias⁶² could have led HCWs to present an idealised image of their work, particularly given their dependency relationships with NGOs and donors.⁶³ Similar pressures to demonstrate success and secure funding are well-documented in the global health sector.⁶⁴ Additionally, practical and time constraints posed challenges to conducting realist interviews,⁶⁵ partly due to limited training time for investigators and perceived power dynamics between interviewers and participants. Such challenges have been highlighted

in other studies.⁶⁶ To mitigate these limitations, several strategies were implemented. Investigators explicitly clarified their independence from the NGOs involved, encouraging participants to speak freely and anonymously. Furthermore, triangulation of data sources was used to cross-verify information and enhance the reliability of the results.

Despite these limitations, this study provides one of the first applications of realist evaluation to explore the individual adoption of a technological innovation in PHC settings. It offers a solid foundation for future research on the dynamics of technology adoption in similar contexts.

CONCLUSIONS

This study suggests that POs are generally used and even adopted by HCWs in decentralised contexts, especially where diagnostic tools are scarce, and their benefits for patient care are observable. Its use enhances diagnostic confidence and reinforces perceptions of its utility. However, structural and institutional challenges, including supply, maintenance, staff training and access to hospital for oxygen treatment, may threaten its long-term integration into health systems. Addressing these barriers will be essential to ensure the sustainability of the PO and its impact on child health outcomes.

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Acknowledgements We thank all the participants of this study, as well as the healthcare staff involved in the AIRE project. We also express our gratitude to the field project staff and the AIRE Research Study Group. We thank the Ministries of Health of the participating countries for their support. Finally, we thank Flore-Apollone Roy for creating the map presented in figure 1.

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Funding The AIRE project is funded by UNITAID (Grant number 2019-34-AIRE), with in-kind support from Institut National de la Santé et de la Recherche Médicale (INSERM, France), and Institut de Recherche pour le Développement (IRD, France). UNITAID was not involved in the design of the study, the collection, analysis and interpretation of the data, nor in the writing of the manuscript.

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Competing interests VR is a member of the Editorial Board of the journal BMJ Global Health. He was not involved in the peer review or handling of the manuscript. All other authors have no competing interest to declare.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Consent obtained from parent(s)/guardian(s).

Ethics approval This study involves human participants. Ethics approval and consent to participate in the AIRE research protocol, the information notice (translated in vernacular languages), the written consent form and any other relevant document have been submitted to each national ethics committee, to the Inserm Institutional Evaluation Ethics Committee (IEEC) and to the WHO Ethics Review Committee (WHO-ERC). All the aforementioned ethical committees reviewed and approved the protocol and other key documents (Comité d'Éthique pour la Recherche en Santé (CERS), Burkina Faso no 2020-4-070; Comité National d'Éthique pour la Recherche en Santé (CNERS), Guinea no 169/CNERS/21; Comité National d'Éthique pour la Santé et les Sciences de la vie (CNESS), Mali no 127/MSDS-CNESS; Comité National d'Éthique pour la Recherche en Santé (CNERS) Niger no 67/2020/CNERS; Inserm IEEC no 20-720; WHO-ERC no ERC.0003364). This study has been retrospectively registered by the Pan African Clinical Trials Registry on 15 June 2022, under the following Trial registration number: PACTR202206525204526. Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. The datasets generated and analysed during the current study are not publicly available. Access to processed deidentified participant data will be made available to any third party after the publication of the main AIRE results stated in the Pan African Clinical Trial Registry Study statement (PACTR202206525204526, registered on 15 June 2022), on a motivated request (concept sheet), and after the written consent of the AIRE research coordinator (Valérie Leroy, valeriane.leroy@inserm.fr, Inserm U1295 Toulouse, France, orcid.org/0000-0003-3542-8616), obtained after the approval of the AIRE publication committee, if still active.

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