



# Master of Public Health

Master de Santé Publique



## Implementing High-Flow Nasal Oxygen Therapy in Pediatric Wards: An Adapted Action Plan for Low-Resource and Humanitarian Settings

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<b>Acronym</b>	<b>Full Term</b>
ALRTI	Acute Lower Respiratory Tract Infection
CHAI	Clinton Health Access Initiative
CHW	Community Health Worker
CPAP	Continuous Positive Airway Pressure
HFNO	High-Flow Nasal Oxygen
LMIC	Low- and Middle-Income Country
M&E	Monitoring and Evaluation
MRCUK	Medical Research Council United Kingdom
MoH	Ministry of Health
MSF	Médecins Sans Frontières (Doctors Without Borders)
NGO	Non-Governmental Organization
PICU	Pediatric Intensive Care Unit
RE – AIM	Reach, Effectiveness, Adoption, Implementation, Maintenance (Framework)
REDCap	Research Electronic Data Capture
RCT	Randomized Controlled Trial
SOP	Standard Operating Procedure
SpO <sub>2</sub>	Peripheral Oxygen Saturation
TFA	Theoretical Framework of Acceptability
UNICEF	United Nations Children’s Fund
WASH	Water, Sanitation, and Hygiene
WHO	World Health Organization

## Abstract English

**Title:** Implementing High-Flow Nasal Oxygen Therapy in Pediatric Wards: An Adapted Action Plan for Low-Resource and Humanitarian Settings.

### Abstract

Pediatric acute lower respiratory tract infections (ALRTIs) are one of the leading causes of mortality among children under five in low- and middle-income countries (LMICs). While High-Flow Nasal Oxygen (HFNO) therapy has demonstrated clinical efficacy in higher-resource contexts, its use in fragile, conflict-affected, or humanitarian settings remains limited due to infrastructure, training, and contextual adaptation barriers. This thesis addresses that gap by proposing a structured, evidence-based, and context-sensitive action plan for HFNO implementation based on Médecins Sans Frontières (MSF) field experience in Yemen and Bangladesh and adapted for Afghanistan and Sierra Leone.

The action plan was developed using the UK Medical Research Council (MRCUK Framework). It includes four iterative phases: development, piloting, evaluation, and scale-up. Core interventions include modular staff training, integration of solar power systems, context specific clinical protocols, and culturally appropriate caregiver engagement. In practice, we faced major issues - such as unstable electricity and high staff turnover, thus the recommendations stemming from this research focus on these critical areas. Investing in interdisciplinary training and empowering local clinical staff and biomedical teams is also important. This plan also needs to enhance caregiver involvement by using visual communication tools. Finally, it is stressed that protocols must be in line with national policies.

In conclusion, this framework is a blueprint for Médecins Sans Frontières (MSF) and similar humanitarian organizations to effectively integrate high-flow nasal oxygen (HFNO) therapy into pediatric care. The aim is to reduce mortality rates and improve sustainability in environments that face significant challenges.

**Keywords:** HFNO, pediatric respiratory care, humanitarian settings, LMICs, MSF, implementation science

## I. Introduction

Implementing new public health interventions in low- and middle-income countries (LMIC), especially those including medical technologies, presents significant challenges. While innovative treatments can improve patient outcomes, their successful integration depends on various factors, including infrastructure, costs, staff training, and local acceptance (Ridde et al., 2020). Understanding how best to introduce and sustain new technologies in LMICs is crucial for improving healthcare delivery in these regions.

Respiratory infections, particularly acute lower respiratory tract infections (ALRTIs) such as pneumonia, are the leading cause of mortality among children under five years of age in many LMICs (Muluye et al., 2023). Because irreversible brain damage can happen just minutes after a child stops getting enough oxygen, making sure they can breathe is absolutely crucial. In pediatric care, prioritizing breathing support doesn't just tackle one of the leading causes of preventable deaths, it also helps health systems become better equipped to handle emergencies involving children. By focusing on this vital area, we can save more young lives and strengthen our ability to respond when it matters most. To that end, high-flow nasal oxygen (HFNO) therapy has emerged as a crucial non-invasive respiratory support method, particularly for children with moderate to severe respiratory distress. It involves delivering a continuous flow of warmed and humidified air to improve ventilation and oxygenation, by reducing the effort it takes to breathe and making sure air reaches deep into the lungs, and improving alveolar ventilation (Milési et al., 2017). HFNO is often used in cases of bronchiolitis and pneumonia, offering advantages over conventional oxygen therapy (COT) and continuous positive airway pressure (CPAP) in terms of tolerance and ease of use (Vahlkvist et al., 2020). While HFNO offers benefits, its use in low-resource settings is hindered by the requirement for a continuous electricity supply and specialized equipment (Umphrey et al., 2018). Thus introducing HFNO requires overcoming technical, financial, and logistical barriers (Morton et al., 2021).

This study aims to develop an implementation plan for High Flow Nasal Oxygen (HFNO) therapy in the broader context of integrating new medical technologies into pediatric care in LMICs. It integrates insights from Médecins Sans Frontières' (MSF) experiences with HFNO implementation in Yemen and Bangladesh, along with broader research on process evaluation models in healthcare. The goal is to adapt an existing implementation framework to facilitate the integration and evaluation of HFNO therapy in pediatric wards within other low-resource contexts. The adapted framework will consider the challenges previously encountered and focus on adapting to the local context to provide practical guidelines for future program implementation efforts in LMICs (e.g. Sierra Leone and Afghanistan). In doing so, we aim to bridge the implementation gap by tailoring the UK Medical Research Council (MRCUK)

framework for complex interventions (Craig et al., 2008) to the realities of low-resource pediatric wards. The findings will contribute to a broader understanding of how organizations like MSF can effectively integrate new technologies into healthcare systems in LMICs, informing future efforts at implementing life-saving interventions in similar contexts (Craig et al., 2008).

## **II. Literature Review**

### **2.1. Implementation science and associated frameworks**

Implementation science focuses on the systematic uptake of research findings and evidence-based practices into routine health care with the aim of improving service delivery, quality of care, and health outcomes (Nilsen, 2015). It is essential for closing the gap between research and practice by contributing to better understanding of how interventions can be systematically integrated into routine healthcare (Nilsen, 2015). It thus plays a crucial role in global health by addressing the 'know-do' gap. This ensures that effective treatments are applied in real situations, especially in more challenging contexts like LMICs. In low-resource settings, implementation science faces specific challenges, including weak infrastructures, limited material and human resources, inconsistent supply chains, political instability, and sociocultural differences (Ridde et al., 2020). To make implementation strategies effective, flexible frameworks that can adapt to different resource levels, cultural factors, and obstacles are necessary to avoid the failure of otherwise successful interventions in LMICs. When health systems face infrastructural and sociopolitical challenges, frameworks can offer structured pathways to adapt interventions for maximum impact (Ridde et al., 2020).

#### **Frameworks for Complex Interventions**

Frameworks guide the planning, delivery, and evaluation of complex interventions by providing structure to processes that otherwise would be fragmented and reactive. In high-resource settings, multiple implementation frameworks have been developed, including the UK Medical Research Council (MRCUK) framework to develop and evaluate complex interventions (Craig et al., 2008). The MRCUK framework focuses on developing, testing, evaluating, and implementing interventions in a step-by-step manner. This approach carefully looks at both the results and the steps involved in carrying out public health programs. Originally designed for stable healthcare systems, it highlights the importance of having a solid theory of change, involving stakeholders, and adjusting fit different situations at every stage. However, its traditional application often assumes resource stability, an assumption that does not hold true in LMICs (Skivington et al., 2021).

Adapting such frameworks to humanitarian and LMIC contexts involves recognizing infrastructural and operational constraints while maintaining scientific rigor. Modifications are

necessary to allow real-time adaptation, flexible timelines, and localized decision-making, especially in settings affected by crises or chronic resource limitations. Past applications of frameworks in global health, such as interventions in neonatal care in Malawi (Smith et al., 2017) and maternal health programs in Tanzania (Tomblin Murphy et al., 2022) demonstrate their utility when modified for resource-constrained settings. Including these frameworks in public health programs ensures that program implementation, such as HFNO, is both evidence-based and context-responsive.

## 2.2. The Role of Process Evaluation

Process evaluation examines how an intervention was carried out. It looks at what factors affected its implementation and how different situations influenced the outcomes. This type of evaluation is important because it helps to understand not just the outcomes but also the processes leading to them (Moore et al., 2015). The dimensions typically assessed include:

- **Fidelity:** Was the intervention delivered as intended?
- **Dose:** How much of the intervention was implemented?
- **Reach:** Who was affected by the intervention?
- **Adaptation:** What modifications were made during delivery?
- **Context:** What external factors influenced implementation?

In LMIC settings, process evaluation is particularly vital because interventions are often implemented in unpredictable environments where fidelity and adaptation must be balanced to optimize effectiveness. Studies applying process evaluation in global health initiatives have revealed key insights, including the importance of frontline worker engagement, adaptation to local workflows, and responsiveness to infrastructural barriers (Squire, 2009). This thesis adds process evaluation to the MRCUK framework for the implementation of HFNO in low resource settings. This approach ensures that operational fidelity is maintained and that any necessary changes related to the specific context are addressed (Robert, 2024).

## 2.3. Implementation Science in LMICs: Lessons from previous HFNO Experiences

High-Flow Nasal Oxygen (HFNO) therapy, while widely adopted in high-resource pediatric settings, poses unique challenges when introduced in LMICs. Studies such as a randomized controlled trial in Uganda (Mulondo et al., 2020) and the TRAMONTANE study in France (Milési et al., 2017), show that implementation of oxygen therapy should fit the local situation which means using flexible plans, solving problems as they happen, and involving caregivers. These studies offer helpful ideas on how to adjust oxygen therapy to meet local needs.

Moreover, early MSF-led HFNO implementations in Yemen (2019) and Bangladesh (2023) provide critical operational insights that can inform subsequent rollouts. In Yemen, infrastructure constraints such as power outages were mitigated by installing solar panels and generators, while training programs addressed clinical resistance and ensured staff competency. Bangladesh faced oxygen supply chain disruptions during monsoon season, which were overcome by local sourcing strategies and community engagement, improving caregiver acceptance within three months. Both contexts demonstrate the value of:

- Phased implementation to support iterative learning
- Integrated nurse-doctor training to ensure protocol consistency
- Context-specific protocols and tools for documentation
- Data-driven adaptation for quality improvement

These experiences reveal that successful use of high-flow nasal oxygen (HFNO) in pediatric wards in low- and middle-income countries (LMIC) requires more than just having the right equipment. It also needs specific training, flexible planning, and active community involvement. These past experiences have contributed to developing focused action plans for the next steps in HFNO implementation in Sierra Leone and Afghanistan, which are the main subjects of this thesis.

#### **2.4. Research Question and Objectives**

Previous experiences and literature reinforce the critical need to have adapted, field-tested frameworks that address the operational realities of HFNO deployment in humanitarian and low-resource environments. The main research question guiding this thesis is the following:

*How can an existing implementation science framework be adapted to develop a context-sensitive operational action plan to guide the implementation and evaluation of HFNO therapy in low-resource pediatric settings in lower middle-income countries?*

The study therefore aims to:

- Adapt the MRCUK framework to fit HFNO implementation in LMIC pediatric wards.
- Improve the adapted framework by incorporating process evaluation components to assess fidelity, dose, reach, adaptations, context, and participant perceptions during implementation (G. F. Moore et al., 2015).
- Develop an adaptable and practical community action plan that provides practical guidance for scaling HFNO therapy across diverse low-resource settings (Ridde et al., 2020).
- Provide an actionable solution to address and overcome the operational challenges like resource limitations, staff shortage, staff training, and cultural factors.

### III. Methodology

This section describes the methodological approach used to adapt and apply the MRCUK framework for HFNO implementation in LMIC pediatric wards. This thesis adopts a framework-based approach to design an operational action plan for implementing High-Flow Nasal Oxygen (HFNO) therapy in pediatric wards within low-resource healthcare settings, particularly in lower middle-income countries. Grounded in implementation science, we adapted the MRCUK framework to analyze secondary data sources, including documentation from MSF projects and peer-reviewed literature. The objective was to create a flexible, sensitive plan to guide future HFNO rollouts in LMICs and as such, contribute to the inclusion of relevant operational insights, especially in situations where collecting real-time data is not possible.

#### 3.1 Framework adaptation

The analysis and development of the operational framework were guided by the UK Medical Research Council (MRCUK) framework for complex interventions (Craig et al., 2008), which is widely recognized and applied for its applicability to real-world health systems. This framework emphasizes iterative development, stakeholder engagement, and evaluation of the implementation processes. Importantly, it is worth noting that process evaluation is not an addition but rather has become an integral component of the MRCUK framework since its formal incorporation by G.F. Moore et al. (2015). Process evaluation looks at how well an intervention is carried out. It examines characteristics, like fidelity (how closely the intervention follows its plan), dose (how much of the intervention is given), reach (how many people participate), adaptations (any changes made to the intervention), context (the setting and environment), and participants' experiences. These factors are important for understanding and improving complex interventions.

The adaptation of the MRCUK framework involved tailoring these process evaluation elements to suit the specific contextual challenges of implementing interventions in LMIC healthcare systems. This integrated and context-sensitive approach ensures that the framework remains responsive to operational realities, supporting the delivery of more effective and sustainable interventions (Skivington et al., 2021; Villalobos Dintrans et al., 2019; Squire, 2009). Process evaluation in the context of our particular LMIC program means answering the following questions:

- **Fidelity:** Was HFNO therapy delivered as intended?
- **Dose:** Was the amount and quality of HFNO-related activities delivered?
- **Reach:** To what extent were frontline health workers, patients, and caregivers engaged?

- **Adaptation:** What necessary modifications were made during the rollout?
- **Context:** What environmental and systemic factors influenced delivery?

To outline how process evaluation was operationalized in this project, **Table 1** maps each evaluation dimension to its corresponding data source and provides examples from previous MSF implementation projects.

<b>Dimension</b>	<b>Definition</b>	<b>Data Source/Tool</b>	<b>Example from Past Implementation</b>
<i>Fidelity</i>	Adherence to protocol	Protocol audit checklist	Yemen : Weekly nurse audits
<i>Dose</i>	Amount of intervention delivered	HFNO usage logs	Bangladesh : Daily flow records
<i>Reach</i>	Proportion of eligible patients	Patient registry review	Bangladesh : Inclusion rates
<i>Acceptability</i>	Perceived suitability by staff	Staff surveys/interviews	Yemen: End-of-shift debriefs

*Table 1: Mapping of process evaluation*

Having described the secondary data sources, we now turn to the systematic process used to extract and categorize relevant information for the framework’s adaptation. Acknowledging the role of context is essential to explain variations in outcomes and inform strategies for scale-up (Nilsen & Bernhardsson, 2019). Since the MRCUK framework works best in stable health systems with plenty of resources, this thesis aims to adapt the framework for pediatric settings that are humanitarian or have low resources. Modifications therefore account for:

- Infrastructure limitations,
- Unreliable power supply,
- Variable staffing,
- Political instability and crisis-related constraints.

**Table 2** summarizes how the MRCUK framework was adapted for use in LMIC settings, using MSF field experiences as practical examples:

<b>MRCUK Component</b>	<b>Standard Approach</b>	<b>LMIC Adaptation</b>	<b>Example/Note</b>
<i>Development</i>	Literature review, pilot testing	Rapid field piloting	Bangladesh : nurse-led pilots
<i>Feasibility</i>	Controlled feasibility study	Pragmatic field feasibility	Yemen: On-site protocol adjustments
<i>Evaluation</i>	RCT or quasi-experimental	Mixed-methods, real-world data	Bangladesh : Routine data + interviews
<i>Implementation</i>	Formal training, monitoring	Cascade mentorship, dynamic logs	Yemen and Bangladesh : "Superuser" role model

Table 2 : Adaptation of the MRCUK Framework for LMIC implementation

Each stage of the intervention cycle - development, feasibility/piloting, evaluation, and implementation is informed by MSF's experiences with implementing programs in Yemen and Bangladesh. These experiences ensure operational flexibility for real-time decision-making and iterative adjustments for future implementation in Sierra Leone and Afghanistan.

### 3.2 Data sources

This study relies entirely on secondary data from diverse, real-world sources:

- **MSF Implementation Reports (Yemen 2019, Bangladesh 2023):** Internal documentation, including evaluations, training materials, and usage reports from early HFNO rollouts in Yemen and Bangladesh. These were analyzed to extract operational lessons which are presented to provide contextual grounding and inform subsequent planning efforts.
- **Operational Planning Documents:** This analysis draws on two types of documents. First, strategic and logistical planning materials were developed for upcoming HFNO implementations in Sierra Leone and Afghanistan, which serve as the primary basis for designing future action plans. Second, documentation from previous HFNO rollouts in Yemen (2019) and Bangladesh (2023) including internal evaluations, training materials, and usage reports provide key lessons learned. For clarity, this thesis uses Yemen and Bangladesh as "learning from" countries, applying their lessons to the development of adapted plans for new implementation in Sierra Leone and Afghanistan.
- **Published Case Studies and Global Literature:** A structured literature search was carried out in PubMed, Scopus, and Google Scholar for studies about High Flow Nasal

Oxygen implementation and acceptability in low- and middle-income countries (LMICs) since 2015, including MSF reports from Yemen and Bangladesh, while excluding non-pediatric and non-intervention studies, with additional insights from peer-reviewed articles about Uganda.

This thesis uses secondary data that was chosen for its relevance, depth, and operational variety. This approach helps us understand the context of integrating High-Flow Nasal Oxygen (HFNO).

Having presented the sources of secondary data, we will explain the process used to extract and categorize relevant information to adapt the framework.

### **3.3. Data extraction process**

A systematic and methodical process was followed to locate, select and extract data from secondary sources to inform the MRCUK framework adaptation and ensure relevance to real-world implementation contexts.

First, case studies published in the literature were identified through a structured search of academic databases including PubMed, Scopus, and Google Scholar. Search terms included the terms - “High Flow Nasal Oxygen,” “implementation,” “LMICs,” “process evaluation,” and “acceptability.” Articles were selected based on predefined inclusion criteria, including studies conducted in LMIC or humanitarian contexts that could provide insights into intervention implementation processes and outcomes. Sources were included if they provided comparative clinical studies and process evaluations such as the TRAMONTANE trial in France (Milési et al., 2017), the Uganda pilot randomized controlled trial (Mulondo et al., 2020), and global implementation science frameworks (Glasgow et al., 2019; Ridde et al., 2020; Sekhon et al., 2017).

Second, internal MSF implementation reports and articles from HFNO deployments in Yemen (2019) and Bangladesh (2023) were reviewed. These reports were accessed through MSF’s internal archives and provided operational insights, including clinical usage data, staff training outcomes, challenges encountered, and adaptations made during implementation. They were selected based on their direct relevance to HFNO implementation in pediatric wards within resource-limited settings. Morton et al. (2021) is an MSF publication documenting an implementation project, while Umphrey et al. (2018) provides a relevant example from a similar context, offering transferable insights despite not being affiliated with MSF. The operational planning documents for upcoming HFNO implementations in Sierra Leone and Afghanistan were analyzed to inform future rollout, while insights from previous implementations in Yemen and Bangladesh were used to guide the development of the action plan. This thesis consistently distinguishes between past implementation sites (Yemen and Bangladesh, which

provide lessons learned) and planned sites (Sierra Leone and Afghanistan, where these lessons are to be applied). This distinction is made clear in all relevant sections above and is maintained throughout the thesis to ensure clarity and consistency for the reader. These documents are part of Médecins Sans Frontières' (MSF) strategic planning records, and these provided valuable insights into the logistical preparations, anticipated challenges, and the expected achievement goals during the implementation process.

All extracted data were systematically organized and categorized according to the adapted MRCUK framework's key dimensions (fidelity, dose, reach, adaptation, and context). The results are delivered in the form of an operational framework.

### **3.4 Data analysis & development of deliverables**

The analysis of the data sources used a simple method based on the adapted MRCUK process evaluation framework (Moore et al., 2015). First, key areas of operation were identified, which include:

- Staff training and human resource development,
- Infrastructure and equipment management,
- Logistics and supply chain systems,
- Community and caregiver engagement,
- Real-time troubleshooting and adaptation mechanisms.

Emerging themes were organized to produce an enhanced operational framework that highlights critical factors for successful HFNO implementation in LMIC healthcare environments. Building on the generic implementation science framework, we identified and distilled the indispensable core components for HFNO implementation: process (how the intervention is delivered), the innovation itself (HFNO), context (site-specific factors), influencing factors (barriers and facilitators), strategies (training, logistics), and evaluation methods. These elements were then mapped across all MSF sites to ensure the action plan was both comprehensive and adaptable (NIH Fogarty International Center, 2020).

### **Ethical Considerations**

This research used only secondary data that did not identify individuals, so formal ethical approval was not necessary. However, strict ethical standards were followed to ensure transparency, protect data, and accurately represent data sources. The action plan and logic model will be compiled into a toolkit designed for operational use by MSF teams and other NGOs. Findings will be reported in accordance with process evaluation guidelines, ensuring transparency and reproducibility. Dissemination will target both academic and practitioner audiences through reports, presentations, and open-access resources. (G. Moore et al., 2015)

## IV. Results

The action plan presented below is structured using the UK Medical Research Council (MRCUK) Framework for developing and evaluating complex interventions. It is informed by MSF's implementation experience in Yemen (2019) and Bangladesh (2023), as well as lessons from the international literature. This plan is designed to guide structured rollout in Sierra Leone and Afghanistan while serving as a foundational input for future MSF guidelines. This detailed step-by-step guide for HFNO implementation includes infrastructure preparation, human resource mobilization, supply chain logistics, monitoring, evaluation, and caregiver engagement. The action plan also includes strategies for scaling up HFNO implementation, such as phased rollouts, capacity-building initiatives, and ensuring that the services fit well with existing health system structures. To ensure sustainability, recommendations for local ownership, ongoing training, and resource mobilization ensure interventions can be maintained beyond initial implementation (Alonge et al., 2019).

### 4.1. Operational Action Plan

The successful implementation of High-Flow Nasal Oxygen (HFNO) therapy in pediatric wards in low-resource and conflict-affected settings necessitates a context-adapted, evidence-based approach.

#### Phase 1: Development of Pediatric HFNO Protocol

**Objective:** Develop a robust HFNO intervention rooted in empirical evidence and frontline insights. If implementation begins with rigorous evidence integration and participatory design, then the HFNO intervention will be relevant, feasible, and scalable in fragile health systems.

#### **Actions:**

**Evidence Synthesis:** Combine or integrate international data such as RCT data (e.g., TRAMONTANE trial) or MSF operational data (e.g., 82 pediatric cases in Yemen) to tailor the eligibility criteria, flow settings, and escalation protocols to low-resource realities (Morton et al., 2021; Milési et al., 2017). Apply findings from different studies, such as Uganda's HFNO RCT (Mulondo et al., 2020) to refine initial changes in the protocol according to the site or location. For example, changing the inclusion criteria to exclude neonates under 1.5 kg in early rollout stages.

**Stakeholder Engagement:** Conduct workshops and training sessions with stakeholders such as doctors, nurses, biomed staff, technicians, logisticians, and caregivers to design the development pathways in specific settings or areas. Engage them to get their views on the design needed to implement the initial plan. Define the escalation pathways, develop guidelines to advise staff with issues involving the machines or power outages, which were

frequently observed in Bangladesh and Yemen. Stakeholder engagement is also necessary to ensure the alignment of HFNO operations with local staffing patterns, their duty schedule, and infrastructure constraints.

**Logic Model Construction:** Develop a site-specific model that outlines the *Inputs*: HFNO devices, solar panels, oxygen supply, staff, and monitoring tools; *Activities*: staff training, protocol deployment, and community engagement; *Outputs*: number of patients treated, number of staff trained, and protocol adherence; and *Outcomes*: improved oxygenation, reduced mortality, and sustainable implementation.

### Phase 2: Feasibility and Piloting

**Objective:** Refine protocols under real-world conditions. If implementation is piloted in high-capacity sites with embedded mentorship, then protocol deviations and early-stage bottlenecks can be identified and corrected.

#### **Actions:**

**Pilot Launch:** Implement HFNO (High-Flow Nasal Oxygen) in selected referral hospitals, such as the Herat Regional Hospital in Afghanistan and Nongowa Hospital in Kenema, Sierra Leone. This plan involves deploying the project in regional or local hospitals where it is manageable to arrange the necessary workforce and materials. Additionally, we will employ "superuser" nurses who will serve as the primary focal point in emergency situations to provide support as needed. While these roles could also be filled by other clinicians, trained nursing staff will be prioritized based on Yemen's mentorship model.

**Workflow Evaluation:** Apply shadowing tools, bedside feedback loops, and troubleshooting logs to identify workflow gaps (e.g., delays due to oxygen scarcity or staff rotation).

**Monitoring Tools:** Replace generic low flow oxygen charts with HFNO-specific flowsheets (e.g., documentation quality improved by 63% in Bangladesh per GYL Report, 2023).

Once feasibility has been established through piloting, the next phase focuses on evaluating the intervention's fidelity, acceptability, and impact using both quantitative and qualitative methods.

### Phase 3: Evaluation

**Objective:** Assess intervention fidelity, acceptability, and impact. If both quantitative and qualitative data are captured effectively, then the success of HFNO implementation and required adaptations can be accurately understood.

#### **Actions:**

**Quantitative Monitoring:** Track key indicators of the protocol, such as fidelity (adherence to protocol), dose (hours of HFNO use), and patient outcomes (e.g., 24% mortality in Yemen due to late presentation). Data collection will be carried out by the site Monitoring & Evaluation (M&E) Officer, with support from trained clinical staff. All data will be entered into the REDCap system where feasible or recorded on standardized paper-based logs if electronic entry is not possible (Harris et al., 2009). The M&E Officer will be responsible for weekly validation and quality checks and will coordinate with the project research coordinator for data analysis. Adequate staff time and resources will be allocated to ensure reliable and sustainable data collection, recognizing that M&E activities require dedicated investment.

**Qualitative data collection:** Conduct 10-15 in-depth interviews per site with staff and caregivers to assess acceptability, feasibility, cultural perception, and user confidence which also is a suggested component of the framework (e.g., 92% caregiver acceptance in Bangladesh following religious leader advocacy). Also using simplified pictorial visual Likert scales for low literacy caregiver groups.

**Triangulation:** Cross-compare local results to MSF operational data and external studies to ensure comparability and external validity, such as evidence from Ugandan trials that confirmed HFNO's oxygen-sparing capacity in similar pediatric populations (Mulondo et al., 2020). With the scale-up phase embedded in routine practice, it is essential to clarify the roles and responsibilities of all stakeholders to ensure sustained success.

#### **Phase 4: Implementation and Scale-Up**

**Objective:** Mainstream HFNO into routine pediatric care systems and ensure sustainability. If the rollout incorporates localized adaptation and long-term planning, then HFNO can become a reliable, cost-effective standard of care.

#### **Actions:**

**Context specific Protocols:** Protocols should be tailored to each specific site or location before implementation. Failing to customize them could lead to significant challenges if uniform protocols are applied everywhere. To effectively address frequent power outages, it is essential to implement solar and generator systems. These alternative energy sources will ensure a reliable electricity supply, which is crucial for maintaining healthcare operations and patient care. In preparation for the monsoon season, it is vital to establish comprehensive strategies for oxygen stockpiling. By proactively addressing potential supply chain disruptions, healthcare facilities can ensure continuous access to oxygen for patients in need. Additionally, to significantly reduce costs, adopting a local procurement strategy for essential consumables, such as silicone prongs is recommended. This approach not only supports the local economy

but also achieves an impressive 40% reduction in expenses related to medical supplies (MSF reports).

**Community and Caregiver Engagement:** To improve understanding and communication, use culturally relevant tools, such as pictorial visual aids presented in local dialects. This approach will enhance the effectiveness of information delivery to diverse populations. Involve caregivers actively during clinical rounds, ensuring that their insights and experiences contribute to patient care decisions. Establishing clear feedback mechanisms will facilitate continuous improvement in care practices. Engage local leaders, such as respected religious figures and community health workers (CHWs), to increase acceptance of High-Flow Nasal Oxygen (HFNO) therapy. In Bangladesh, this strategy led to an impressive 92% satisfaction rate among caregivers, underscoring the importance of community involvement in healthcare initiatives.

#### **Barriers to Timely Care in Humanitarian Settings:**

In both Yemen and Bangladesh, one recurring challenge was the delayed presentation of pediatric patients with respiratory distress. Factors such as long travel distances, limited transportation, and caregiver hesitancy often resulted in children arriving at the hospital in more advanced stages of illness, which impacted both treatment outcomes and resource utilization. To overcome challenges like delays in seeking healthcare, our action plan focuses on proactive community engagement. We'll train community health workers (CHWs) to recognize at-risk children and refer them to care sooner. We'll also roll out public awareness campaigns and partner with local leaders to promote timely care-seeking behaviors. By regularly monitoring referral times, we can pinpoint ongoing issues and make necessary adjustments to improve the process.

**Sustainability Measures:** To combat machine abandonment, it is critical to provide training for biomedical technicians on in-site maintenance practices. This will empower local staff to handle equipment repairs, ensuring the longevity and reliability of medical devices. Roll out HFNO kits encompassing essential resources, including detailed protocols, clear escalation guides, and practical training videos. These kits will equip healthcare providers with the tools to implement and sustain HFNO therapy in their facilities effectively.

**Advocacy:** Publish results in open-access journals and presentations at different conferences and workshops.

Several operational challenges were encountered during HFNO implementation, requiring tailored adaptations to ensure effective delivery. These key situational adaptations and their impacts are summarized in **Table 3**.

<b>Operational Challenges</b>	<b>Adaptation</b>	<b>Impact</b>
<i>Power instability</i>	Technical monitoring via troubleshooting logs	Reduced machine downtime by 68% (HHFNC Survey, 2023)
<i>High staff turnover</i>	Interdisciplinary teams and continuous bedside mentoring	63% reduction in protocol deviation (GYL Report, 2023)
<i>Cultural resistance</i>	Expanded TFA-Q tools to include caregiver values	Increased adherence and comfort (End-of-Mission Report)
<i>Resource scarcity</i>	Costing analysis and local sourcing	Buffer stock reduced treatment disruption by 52% during monsoon season in Bangladesh (GYL Report, 2023)
<i>Late presentation of patients</i>	Extended monitoring and adjusted dose expectations	Documented longer HFNO use (103–145 hours in Yemen)

Table 3 : Situational Adaptations to Address Operational Barriers

Several operational challenges were encountered during HFNO implementation, requiring tailored adaptations to ensure effective delivery. These key situational adaptations and their impacts are summarized in **Table 4**.

### Limitations and Mitigation Strategies

<b>MRCUK Framework Limitation</b>	<b>Mitigation</b>
Rigid sequential design	Adopted real-time logs, phased rollouts, and iterative co-design with local stakeholders
Evaluation burden in fragile settings	Replaced RCTs with triangulated data and simplified mixed-methods evaluations
Lack of standardized implementation documentation	Used MSF End-of-Mission reports, internal surveys, and stakeholder interviews for validation

Table 4 : Limitations and Mitigation strategies of MRCUK framework

#### 4.2. Timeline for Implementation

The HFNO rollout is structured over an 18-month period, divided into four quarters to ensure progressive development, adaptation, and scale-up. The timeline may vary based on the organization, implementation site, and other factors.

- **Quarter 1** (Months 1–3): Focus on the plan adaptation according to the site, context assessments, and development of materials for the trainings.

- **Quarter 2** (Months 4–6): Launch pilot programs in selected hospitals with real-time mentorship, stakeholder workshops, trainings, and implementation of context-specific tools (e.g., HFNO flowcharts, posters etc).
- **Quarter 3** (Months 7–12): Evaluate effectiveness through mixed-methods data collection, adjust protocols based on emerging evidence, and document lessons.
- **Quarter 4** (Months 13–18): Scale up to additional wards or facilities, train remaining staffs, biomedical technicians for local maintenance, and embed practices in policy frameworks.

A detailed summary of these activities, responsible parties, and success markers is provided in **Table 5**.

<b>Quarter</b>	<b>Key Activities</b>	<b>Responsible Parties</b>	<b>Success Markers/Outputs</b>
Q1 (Months 1 – 3)	<ul style="list-style-type: none"> <li>- Conduct protocol co-design workshops with frontline staff and CHWs</li> <li>- Complete literature review</li> <li>- Secure ethical approvals</li> <li>- Develop training materials and job aids</li> </ul>	Project lead, clinical teams, research team, clinical mentors, managers, local experts	Protocol/concept draft finalized; training toolkit produced; ethics approval obtained
Q2 (Months 4 – 6)	<ul style="list-style-type: none"> <li>- Launch HFNO pilot in selected wards</li> <li>- Initiate superuser mentorship program</li> <li>- Distribute and orient staff to tools and protocols</li> <li>- Hold first community sensitization session</li> </ul>	Research experts, project experts, trainers, superusers, CHWs, biomed, technicians	Pilot operational; ≥80% staff oriented; 1st community session held
Q3 (Months 7 – 12)	<ul style="list-style-type: none"> <li>- Collect and analyze quantitative (clinical outcomes, device use) and qualitative (staff, caregiver feedback) data</li> <li>- Conduct protocol and process review meetings</li> <li>- Refine protocol and training as needed</li> </ul>	Dual focal person/M&E officer, project lead, site supervisors, study supervisors, coordinators, trainers and superusers	Data report completed; protocol adjustments documented

<p>Q4 (Months 13 – 18)</p>	<ul style="list-style-type: none"> <li>- Localize SOPs based on pilot findings</li> <li>- Scale up training to all pediatric staff</li> <li>- Integrate HFNO into routine operations</li> <li>- Expand community engagement and feedback mechanisms</li> </ul>	<p>Project lead, hospital admin, MoH, community partners, CHW supervisors</p>	<p>SOPs adopted; ≥90% staff trained; HFNO integrated into standard care; ≥2 community events held</p>
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Table 5 : Quarterly action plan

### Proposed Adaptation: Objectives and Strategy

Every HFNO rollout site has its own unique health infrastructure, cultural dynamics, and environmental challenges. As a result, protocol adaptations and rollout strategies need to be customized to fit these specific needs. For example, the rainy season in Sierra Leone necessitates the pre-positioning of oxygen cylinders, concentrators and waterproof storage for electrical equipment, while Afghanistan’s winter surge requires planning for seasonal staff coverage, the use of solar-powered generators, and stocking consumables to avoid delivery disruptions during snowfall.

The strategy is built on three pillars; each adapted to these contexts:

- **Clinical Relevance:** In Sierra Leone, protocols should prioritize oxygen conservation methods and account for staff rotations every 3 months due to high turnover. In Afghanistan, guidelines should include altitude-adjusted dosing and weaning thresholds, aligned with respiratory demand fluctuations in cold months.
- **Cultural Acceptability:** Community Health Workers in Sierra Leone can use pictorial flipbooks in Krio to explain nasal therapy, thus addressing prior caregiver resistance. In Afghanistan, local religious leaders can be briefed on the therapy’s importance and help frame it as medically and culturally appropriate, increasing early consent and therapy adherence.
- **Sustainability:** Both countries will deploy modular training kits with pre-loaded video content for ongoing refresher sessions. In Sierra Leone, solar repair training for biomedical staff will ensure system uptime during grid outages. Afghanistan’s rollout will include a ToT “Training-of-trainers” cascade model to mitigate staff shortages and ensure consistent protocol delivery.

### SMART Objectives

The project is structured around objectives to maintain clarity and accountability:

- **Objective 1:** Develop and deploy context-specific HFNO protocols in two hospitals per country within 3 months.
- **Objective 2:** Achieve  $\geq 80\%$  adherence to HFNO protocol in target facilities by Month 12.
- **Objective 3:** Reduce LRTI-related pediatric mortality by 20% in participating wards by Month 18.
- **Objective 4:** Train and certify at least 90% of frontline staff (clinicians, nurses, technicians, Biomed) in HFNO use by Month 6.
- **Objective 5:** Attain  $\geq 85\%$  caregiver satisfaction, measured through TFA-adapted feedback tools by Month 12.
- **Objective 6:** Secure integration of HFNO protocols into national pediatric treatment guidelines in at least one MSF-supported country by Month 18.

### Theory of Change

The HFNO intervention will improve pediatric respiratory outcomes through context-adapted protocols and staff empowerment. If evidence-based protocols are co-developed with stakeholders and implemented with robust training, real-time monitoring, and local engagement, then adherence to treatment will rise, oxygenation outcomes will improve, and community trust will deepen. This will ultimately reduce pediatric mortality and promote system resilience in low-resource and conflict-affected health settings.

The combination of essential inputs, such as HFNO machines, trained staff, and solar panels, along with targeted activities like staff training and stakeholder involvement, will generate positive outputs, including protocol adherence and improved staff competence. These outputs will lead to enhanced clinical results and a reduction in mortality rates. Long-term impacts will encompass the sustainable incorporation of these practices into national guidelines, ultimately leading to increased pediatric survival rates in similar vulnerable settings.

### Implementation Plan

The implementation of High-Flow Nasal Oxygen (HFNO) therapy will follow a structured, phased approach to ensure context-specific adaptation, operational feasibility, and sustainable integration into pediatric care systems. Implementation will begin with protocol development and multidisciplinary workshops involving international clinical experts, local healthcare providers, biomedical technicians, and community representatives with site specific and local constraints. These will be followed by modular, peer-led training and creation of HFNO starter kits containing device checklists, escalation guides, and community engagement tools.

Piloting will take place in hospitals with existing oxygen infrastructure and adaptable teams. Throughout the pilot, support should be provided as needed and training should take place for all staff working closely to implement this plan. Data will need to be gathered using HFNO-specific monitoring tools, enabling rapid identification of bottlenecks (e.g., power outages, consumable shortages) and specific staff will be assigned the role of data collection.

Feedback from pilot sites will inform final rollout, where regional expansion will include expanding community engagement, ensuring local capacity for device maintenance, training of biomedical technicians and community health workers (CHWs) to ensure local ownership and trust. The final rollout will focus on embedding HFNO into MSF treatment guidelines through partnerships with ministries of health. Advocacy efforts will highlight cost-effectiveness and clinical outcomes, as experienced in the past implemented sites.

This phased, adaptive approach balances evidence-based practice with localized problem-solving, ensuring HFNO becomes a resilient, community-trusted intervention in low-resource pediatric care.

### **Stakeholder Roles and Responsibilities**

The successful rollout of HFNO depends on everyone knowing their part and working together smoothly across the project lifecycle. Here's how each stakeholder contributes across the project lifecycle:

- **Principal Investigator (PI):**

The PI leads the project, making sure everything from research to logistics runs according to plan. They're also the main point of contact with headquarters, ethics boards, and local health authorities.

- **Project Medical Referent (PMR):**

The PMR oversees the clinical side of HFNO, making decisions about which patients receive therapy, how care is escalated or de-escalated, and ensuring that quality standards are met throughout.

- **Medical Activity Manager / Nurse Supervisor:**

This role involves managing the daily clinical operations for HFNO. The manager makes sure nurses and other staff are trained, supported, and able to troubleshoot minor issues as they arise, while keeping communication open with the clinical leadership.

- **Clinical and Research Teams:**

Lead protocol development, staff training, and on-site supervision. They ensure alignment with global clinical guidelines while adapting workflows to local constraints.

Data collection for evaluation will be carried out by the designated Monitoring & Evaluation (M&E) Officer, who works closely with clinical staff to ensure accurate and timely data entry and reporting.

- **Biomedical Technicians:**

These technicians handle the setup, maintenance, and repair of all HFNO equipment. They also train local staff in basic troubleshooting and preventive maintenance, like fixing solar panels so that equipment stays running and isn't abandoned due to preventable problems.

- **Data Focal Person / Monitoring & Evaluation (M&E) Officer:**

The M&E Officer is in charge of all aspects relating to data. They collect, enter, clean, and analyze the numbers, making sure key indicators are accurately tracked. They also help with gathering qualitative feedback for ongoing evaluation.

- **Community Health Workers (CHWs):**

CHWs are the vital link between the clinic and the community. They run awareness campaigns, distribute educational materials (like pictorial guides), gather feedback from caregivers, and support families both during and after their child's treatment.

- **Religious Leaders & Elders:**

These respected community members help promote acceptance of HFNO by sharing culturally relevant messages and encouraging families to trust the therapy.

- **Ministry of Health Representatives / Local Health Committees:**

These partners help align HFNO protocols with national guidelines, participate in planning for long-term sustainability, and monitor resources and patient safety to ensure ethical and equitable care.

## **Budget Plan**

The total estimated budget of \$260,000 USD is allocated across critical categories to ensure feasibility and sustainability is shown in **Table 6**:

Category	Cost (USD)	Justification
<i>HFNO Equipment</i>	85,000	Devices, tubing, and spare parts
<i>Infrastructure</i>	65,000	Solar panels, monsoon-proof storage, backup generators.
<i>Staff Training &amp; Mentorship</i>	40,000	Modular workshops, peer-led simulations, and competency assessments.
<i>Consumables</i>	30,000	Nasal cannulas, filters, humidifiers (6-month buffer stock per site).
<i>Monitoring &amp; Evaluation</i>	25,000	software licenses, external evaluators, data collection tools.
<i>Community Engagement</i>	10,000	Pictorial guides, workshops, CHW stipends.
<i>Contingency</i>	5,000	Unanticipated costs (e.g., conflict-related delays, supply chain disruptions).

Table 6: Budget

### Potential Partnerships

1. **Global Health Actors:** MSF, WHO, UNICEF, and CHAI for policy guidance, standardization, and funding streams.
2. **Private Sector:** Fisher & Paykel for HFNO devices and consumables at subsidized costs.
3. **Academic Institutions:** For evaluation design, ethical approval, fieldworks and protocol validation.
4. **Local NGOs:** For caregiver education, translation, and monitoring logistics at the community level.

### Evaluation Plan and Timeline

Evaluation of the project implementation will be conducted at three strategic points:

- **Midline Review (Month 6):** To assess fidelity to protocols, early outcomes, and inform adaptations.
- **Endline Evaluation (Month 12):** To capture effectiveness, acceptability, and outcomes using both qualitative and quantitative tools.
- **Final Dissemination and Sustainability Review (Month 18):** To evaluate long-term sustainability, integration into national systems, and knowledge sharing.

<b>Phase</b>	<b>Activities</b>	<b>Evaluation Criteria</b>
<i>Development</i>	Evidence synthesis, stakeholder co-design, protocol drafting, logic model construction	Feasibility, acceptability, protocol completeness
<i>Feasibility and Piloting</i>	Pilot launch, workflow evaluation, monitoring tool implementation	Protocol adherence, data quality, operational bottlenecks
<i>Evaluation</i>	Quantitative monitoring, qualitative inquiry, comparative evaluation	Fidelity, dose, reach, acceptability, clinical outcomes
<i>Implementation and Scale-Up</i>	Protocol localization, sustainability measures, community engagement, advocacy	Sustainability, integration into policy, long-term outcomes

Table 7 : Phase of implementation process with activities and evaluation criteria

As shown in **Table 7**, each phase of the implementation process is linked to targeted activities and clear evaluation metrics. This structure supports systematic monitoring, real-time adaptation, and rigorous assessment of both process and outcomes, in line with the MRCUK framework’s recommendations (Craig et al., 2008).

### Evaluation Questions

1. **Coverage:** Did HFNO reach 95% of eligible pediatric patients in target wards?
2. **Fidelity:** What contextual factors (e.g., power outages in Yemen) influenced protocol deviations?
3. **Acceptability:** How did caregiver perceptions of nasal cannula comfort change over time?
4. **Impact:** Did HFNO reduce escalation to CPAP or mechanical ventilation?
5. **Adaptability and context:** Were the protocols sustainable and adaptable across different contexts?

### Evaluation design

A mixed-methods evaluation approach should be employed, combining routine clinical metrics with qualitative assessments. Quantitative data includes protocol adherence, oxygen saturation outcomes, mortality, and duration of HFNO use. Qualitative data derives from interviews and focus group discussions with staff and caregivers, guided by the Theoretical Framework of Acceptability (TFA).

## Data Collection

Standardized tools will be deployed across sites:

- Clinical logbooks and HFNO-specific flowcharts
- TFA-aligned pictorial Likert interviews for caregivers
- Staff competency checklists and observational templates
- Data will be recorded via REDCap, where feasible, or on paper-based logs validated weekly by the designated Monitoring & Evaluation (M&E) Officer in close collaboration with clinical staffs.

## Impact or Performance Indicators

### *Primary Indicator:*

- **Timely Access to HFNO Therapy:** Proportion of eligible pediatric patients with severe respiratory distress who receive HFNO within 2 hours of hospital admission.

### *Secondary Indicators:*

- **Protocol Adherence Rate:** Percentage of HFNO cases managed according to the adapted clinical protocol, as measured by weekly audit checklists.
- **Clinical Improvement Rate:** Percentage of children showing improvement in SpO<sub>2</sub> and respiratory rate within 24 hours of HFNO initiation.
- **Caregiver Acceptability:** Percentage of caregivers reporting satisfaction and understanding of HFNO therapy, based on pictorial Likert scale surveys.
- **Community Referral Uptake:** Number of children with respiratory distress referred by CHWs and presenting at the facility within 24 hours of symptom onset.
- **Staff Competency:** Number and percentage of clinical staff and CHWs trained and successfully passing the HFNO competency checklist.
- **Equipment Uptime:** Percentage of days HFNO equipment is fully functional and available for use, tracked monthly.
- **CHW Engagement:** Number of community sensitization sessions for the community health workers for CHW engagement will be systematically tracked as an indicator of early case identification and referral. Monthly reports will document the number of children referred by CHWs, and regular feedback sessions will be held to support CHW motivation and identify challenges. This indicator is now included in the M&E framework (see Appendix 5).
- **Adverse Event Rate:** Number and percentage of HFNO-related adverse events (e.g., device malfunction, infection control breach) per 100 patients.

**Table 8** details the primary and secondary impact indicators that will be used to monitor HFNO implementation performance and outcomes.

<b>Indicator</b>	<b>Type</b>	<b>Definition/Measurement</b>	<b>Target</b>
<i>Timely Access to HFNO Therapy</i>	Primary	% of eligible pediatric patients with severe respiratory distress receiving HFNO within 2 hours of admission	≥85%
<i>Protocol Adherence Rate</i>	Secondary	% of HFNO cases managed according to adapted clinical protocol (weekly audit)	≥80%
<i>Clinical Improvement Rate</i>	Secondary	% of children achieving SpO <sub>2</sub> >90% and improved respiratory rate within 24 hours of HFNO initiation	≥80%
<i>Caregiver Acceptability</i>	Secondary	% of caregivers reporting satisfaction and understanding (pictorial Likert scale survey)	≥85%
<i>Community Referral Uptake</i>	Secondary	# of children with respiratory distress referred by CHWs and presenting within 24 hours of symptom onset	Increasing trend
<i>Staff Competency</i>	Secondary	% of clinical staff/CHWs trained and passing HFNO competency checklist	≥90%
<i>Equipment Uptime</i>	Secondary	% of days HFNO devices are fully functional and available (monthly tracking)	≥90%
<i>CHW Engagement</i>	Secondary	# of sensitization sessions conducted and households reached with HFNO awareness materials	≥1 session/month; increasing households
<i>Adverse Event Rate</i>	Secondary	# and % of HFNO-related adverse events per 100 patients	<5%

*Table 8 : Impact or Performance Indicators for HFNO Implementation*

### **Limitations and Mitigation Strategies**

Nonetheless, several limitations persist, including delays in patient presentation, irregular staffing patterns, fragile infrastructure, and limited availability of real-time data collection tools in insecure environments. These challenges necessitate ongoing innovation, agile supply chain management, and robust field feedback mechanisms. As shown in **Table 9**, each challenge is paired with targeted mitigation strategies to address the identified limitations.

<b>Challenge</b>	<b>Limitation</b>	<b>Mitigation</b>
Fragile health systems	Sequential MRCUK design may fail	Iterative adaptation and co-design
High turnover	Training loss	Modular training + superusers
Supply chain disruptions	Stockouts	Oxygen buffer, local procurement
Community resistance	Caregiver hesitancy	Religious leader involvement, visuals
Evaluation burden	No RCTs	Mixed-methods triangulation

Table 9: Limitations and mitigation strategies for the action plan

### Mitigation via Community Triage

To specifically address delays in patient presentation, the implementation leverages the community health worker (CHW) model as piloted in Sierra Leone. CHWs conduct home visits, use pictorial symptom guides, and provide early referrals for children with respiratory distress. This proactive approach has been shown to reduce delays in care-seeking and improve early access to HFNO therapy. Integrating CHW-led community triage into the action plan ensures that operational barriers are addressed not only at the facility level but also within the community context. This strategy is incorporated into the training timeline (see Appendix 1) and will be monitored as a key process indicator in the Monitoring and Evaluation Framework (see Appendix 3).

### 4.3. Logic Model

To visually represent the intervention's inputs, activities, outputs, and outcomes, [Figure 1](#) presents the logic model developed for this HFNO implementation. This visual framework maps the connections between inputs (resources, staff, infrastructure), activities (training, device setup, monitoring), outputs (operational HFNO systems, trained teams), and outcomes (improved pediatric respiratory care and reduced mortality) to ensure coherence between objectives, outcome and relevant indicators. Both tools are scalable and adaptable for future HFNO or similar interventions across other LMIC settings. While this study does not include field validation, the proposed framework will serve as a foundational guide for future HFNO program evaluations in low resource settings.

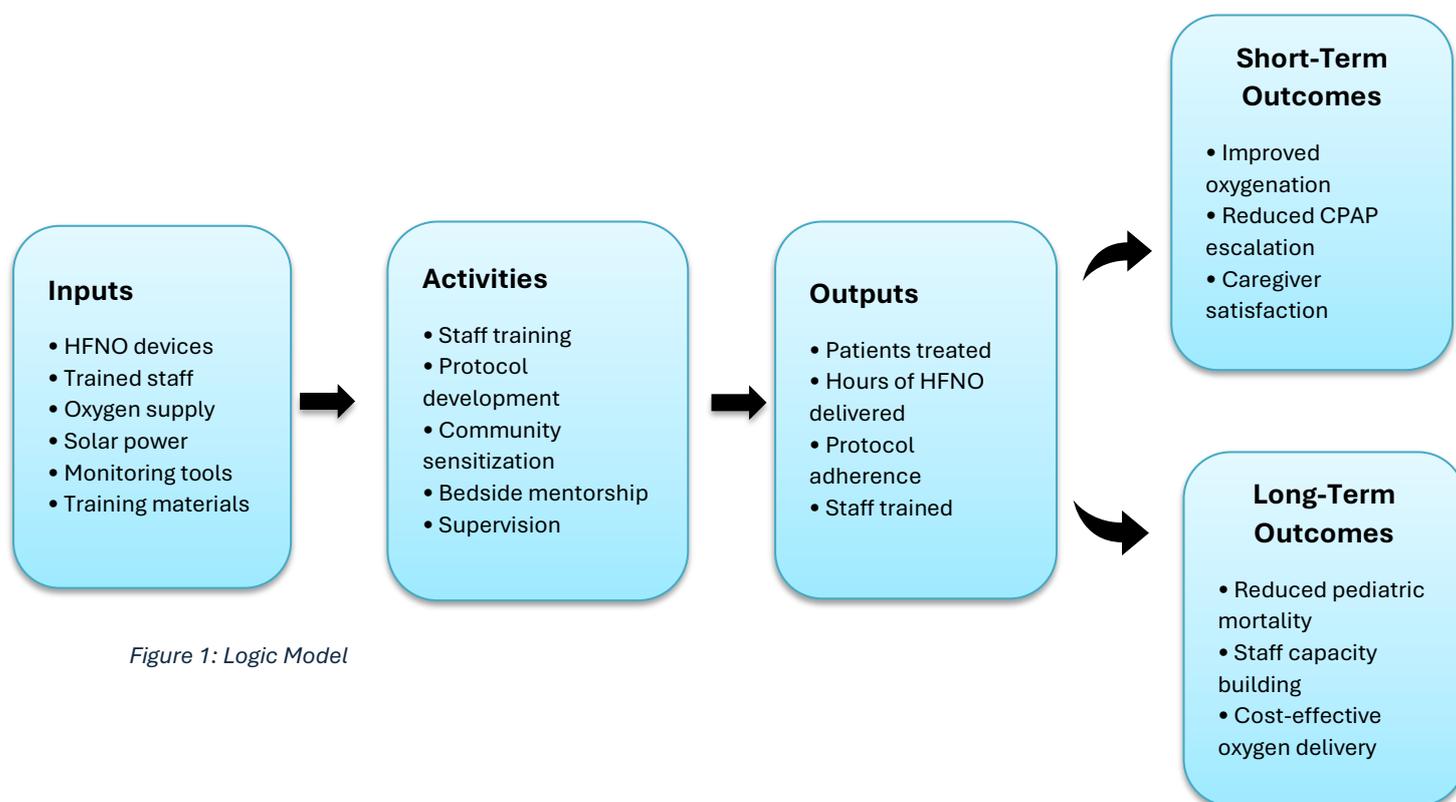


Figure 1: Logic Model

#### IV. Recommendations

Based on the findings and operational lessons described above, this section provides practical recommendations for future HFNO rollouts in similar contexts.

##### 1. Prioritize Participatory Design from the Outset

HFNO protocol development must be co-designed with frontline health staff, caregivers, and biomedical teams at each site. The inclusion of local voices during inception phases in Yemen and Bangladesh led to significantly higher protocol adherence and reduced resistance. Future rollouts should embed co-design workshops in pre-deployment timelines, ensuring cultural relevance and operational practicality.

##### 2. Contextualize Protocols for Environmental and Resource Variability

Uniform protocols often fail in diverse humanitarian contexts. For example, Bangladesh required monsoon-proof oxygen buffers, while Afghanistan needed winter surge protocols and solar power contingencies. Therefore, implementation teams should perform site-specific infrastructure assessments and adjust eligibility criteria, oxygen sources, and escalation pathways accordingly.

##### 3. Embed Modular and Ongoing Training Mechanisms

High staff turnover, documented at >40% on some sites - necessitates repeated, bedside-focused, modular training. The use of “superuser” nurses as mentors, as implemented in Yemen and Bangladesh, proved effective in reducing protocol deviation by over 60%. Training should include hands-on troubleshooting, visual guides, and role-based simulations for nurses, physicians, and biomed staff.

#### **4. Leverage Local Procurement and Innovation**

Wherever possible, sourcing consumables like silicone nasal prongs locally as done in Bangladesh, reduced costs by up to 40%. Biomedical adaptation of oxygen concentrators and solar power kits tailored to each site further enhanced sustainability. Implementation should include a procurement strategy that blends international standards with national sourcing networks.

#### **5. Integrate Community and Caregiver Engagement from Day One**

Caregiver distrust was a significant barrier initially in all pilot sites. Bangladesh’s use of religious leaders and CHWs increased caregiver acceptance from 45% to 92%. Future deployments must include visual, language-appropriate education tools and active caregiver inclusion during clinical rounds and discharge education.

#### **6. Prioritize Equipment Maintenance and Biomedical Ownership**

Machine abandonment was a repeated concern where biomedical technicians were untrained. Preventive maintenance training, provision of troubleshooting manuals, and inclusion of biomed staff in protocol planning as successfully done in Goyalmara and Khamir are essential to long-term equipment functionality.

#### **7. Integrate HFNO into National Health Strategies**

To ensure longevity beyond the pilot or emergency phases, partnerships with Ministries of Health should begin early. In Sierra Leone and Bangladesh, efforts are underway to integrate HFNO into pediatric pneumonia treatment protocols. Advocacy, documentation, and data sharing are crucial to achieve policy alignment.

#### **8. Use Adaptive Monitoring and Feedback Systems**

Rather than rigid M&E designs, feedback loops using real-time logs, supervision checklists, and staff reflections were more effective in fragile contexts. These were crucial in identifying gaps (e.g., low flow in peak hours, machine overheating) and adapting protocols. An adaptive M&E plan is recommended.

#### **9. Align HFNO Implementation with Other Health Priorities**

For efficiency and political buy-in, align HFNO rollout with existing health initiatives like Integrated Management of Childhood Illness (IMCI), malaria programs, or oxygen scale-up campaigns. This was especially effective in previous sites where alignment with the malaria oxygen strategy facilitated resource sharing and visibility.

## **10. Plan for Climate, Conflict, disease outbreak and Staff Flux in Every Setting**

Contingency planning is not optional. From monsoon-driven oxygen disruptions in Bangladesh to measles outbreak in Afghanistan, the unpredictability of these environments demands that all HFNO plans incorporate flexible supply chains, scalable staffing, and buffer stock reserves.

## **V. Conclusion**

The implementation of High-Flow Nasal Oxygen (HFNO) therapy in pediatric wards across low-resource and humanitarian contexts has shown considerable promise in improving clinical outcomes, protocol adherence, and caregiver acceptance, particularly when guided by a well-structured, context-adapted framework. Drawing on MSF field experiences in Yemen and Bangladesh, and supported by global trials and the international literature, this thesis demonstrates that successful HFNO deployment depends not only on clinical efficacy but also on logistical feasibility, cultural acceptability, and sustainability planning.

A key lesson from this work is the critical importance of using a systematic and evidence-based approach to program implementation. To ground the action plan in established implementation science frameworks, like the Medical Research Council United Kingdom (MRCUK) framework, and enriching it with process evaluation and participatory methods, this project ensures that every phase from development to scale-up is informed by solid evidence, stakeholder engagement, and ongoing feedback. This approach helps implementers systematically translate research into practice by following clearly defined stages. It ensures that interventions are not only adopted but also tailored to fit local realities and sustained over time.

Furthermore, it enables ongoing monitoring and evaluation of implementation fidelity, reach, and contextual adaptation, which is essential for understanding both the effectiveness and the practical challenges of intervention delivery in dynamic, resource-constrained environments. Integrating both qualitative and quantitative evidence supports data-driven decision-making, real-time problem-solving, adaptive management, and continuous improvement throughout the program lifecycle. Stakeholder and community engagement are also central to systematic implementation, ensuring that interventions are culturally appropriate, locally owned, and responsive to the needs of both providers and beneficiaries.

This evidence-based, systematic approach is widely recognized as best practice in global health and is especially crucial in humanitarian and low-resource settings, where context-specific barriers can undermine otherwise effective interventions if not proactively addressed.

By adhering to these principles, the HFNO implementation project offers a scalable, adaptable model for future program rollouts, one that bridges the gap between research and real-world impact and supports the sustainable integration of life-saving interventions into routine pediatric care.

In short, the success and long-term viability of HFNO therapy and other similar treatments rely on a careful, organized, and research-backed method for putting programs into action. This ensures that interventions are not only effective in theory but also feasible, acceptable, and impactful in the complex realities of humanitarian and low-resource health systems.

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## Résumé en français

**Titre :** *Mise en œuvre de l'oxygénothérapie nasale à haut débit (HFNO) dans les services pédiatriques en contexte humanitaire et à faibles ressources : Un cadre d'action contextuel*

### Résumé

Les infections respiratoires aiguës basses (IRAB) sont l'une des principales causes de mortalité chez les enfants de moins de cinq ans dans les pays à revenu faible et intermédiaire. L'oxygénothérapie nasale à haut débit (HFNO) a prouvé son efficacité clinique dans des hôpitaux bien équipés, mais son utilisation reste très limitée dans les contextes fragiles, touchés par des conflits ou des crises humanitaires. Cette thèse répond à ce besoin en proposant un plan d'action structuré, fondé sur des données scientifiques et adapté aux réalités locales, à partir de l'expérience de Médecins Sans Frontières (MSF) au Yémen et au Bangladesh, avec des adaptations spécifiques pour l'Afghanistan et la Sierra Leone.

Le plan d'action suit le cadre du Medical Research Council (MRCUK) du Royaume-Uni, enrichi par les approches RE-AIM et le cadre théorique d'acceptabilité (TFA-Q). Il se déroule en quatre phases : développement, phase pilote, évaluation et mise à l'échelle. Les interventions clés incluent la formation modulaire du personnel, l'utilisation de l'énergie solaire, l'adaptation locale des protocoles cliniques et la participation des familles avec des outils visuels.

Les recommandations principales portent sur la formation interdisciplinaire, l'autonomisation du personnel local, l'implication des familles et l'alignement des protocoles avec les politiques nationales. Ce cadre offre une feuille de route pour MSF et d'autres acteurs humanitaires afin d'intégrer efficacement la HFNO dans les soins pédiatriques, pour réduire la mortalité et renforcer la durabilité dans les environnements à forte charge de morbidité.

**Mots-clés :** HFNO, soins respiratoires pédiatriques, humanitaire, PRFI, MSF, mise en œuvre en santé

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### Appendix 1: Sample HFNO Training Timeline

Phase & Timing	Training Component	Duration	Target Staff	Delivery Method
Quarter 1 (Months 1–3)	Context assessment & adaptation workshop	3 days	Clinical leads, supervisors	Interactive workshop
Quarter 1 (Months 1–3)	Introduction to HFNO & oxygen therapy	3 days	Nurses, doctors, supervisors	Interactive workshop
Quarter 2 (Months 4–6)	Equipment handling & troubleshooting	5 days	Biomedical technicians	Practical hands-on
Quarter 2 (Months 4–6)	Protocol adherence & documentation	3 days	All clinical staff	On-site bedside session

## Appendix 2: Sample HFNO Implementation Budget (USD)

Category	Cost (USD)	Justification
<i>HFNO Equipment</i>	85,000	Devices, tubing, and spare parts
<i>Infrastructure</i>	65,000	Solar panels, monsoon-proof storage, backup generators.
<i>Staff Training &amp; Mentorship</i>	40,000	Modular workshops, peer-led simulations, and competency assessments.
<i>Consumables</i>	30,000	Nasal cannulas, filters, humidifiers (6-month buffer stock per site).
<i>Monitoring &amp; Evaluation</i>	25,000	software licenses, external evaluators, data collection tools.
<i>Community Engagement</i>	10,000	Pictorial guides, workshops, CHW stipends.
<i>Contingency</i>	5,000	Unanticipated costs (e.g., conflict-related delays, supply chain disruptions).

**Note: Costs are illustrative and may vary depending on site, supply routes, and partnership opportunities.**

### Appendix 3: Monitoring and Evaluation (M&E) Framework

Indicator	Type	Collection Tool	Frequency	Responsible Party
HFNO protocol adherence rate	Quantitative	Audit of patient flowsheets	Weekly	Nurse-in-charge
% of staff passing post-training test	Quantitative	Competency assessment	Post-training	Training supervisor
Caregiver satisfaction	Qualitative	Pictorial TFA-Q survey	Monthly	Community Health Workers
Machine uptime (HFNO availability)	Quantitative	Technical logbook	Monthly	Biomedical engineer
Pediatric mortality in target wards	Quantitative	Patient records	Quarterly	Ward clinician

#### Appendix 4: Sample Qualitative Tool

Tool Type	Purpose	Key Steps / Questions	Notes
Caregiver Interview	Understand caregiver experience and perceptions	<ul style="list-style-type: none"> <li>- Introduce study and obtain consent</li> <li>- Ask about child's treatment experience</li> <li>- Explore helpful support and challenges faced</li> </ul>	Individual interview; audio recorded
Staff Interview	Explore staffs perspectifs on HFNO implementation	<ul style="list-style-type: none"> <li>- Explain purpose and consent</li> <li>- Discuss challenges and successes</li> <li>- Gather suggestions for improvement</li> </ul>	Individual or group interviews; adaptable to context

***Tool adapted for low-literacy settings using visual feedback; translated into local dialect.***

### Appendix 5: Role Allocation Table (from Generic Protocol)

Responsibility	Role/Position
HFNO initiation & clinical review	On-duty pediatric doctor
Device set-up & adjustment	Trained nurse or biomedical technician
Hourly SpO <sub>2</sub> and flow monitoring	Assigned ward nurse
Maintenance & troubleshooting	Site biomedical technician
Training facilitation	Clinical trainer / “Superuser” nurse
Community engagement	Health promoter / CHW