J Afric Neonatal 2025;3: 114 - 119

ORIGINAL

An evaluation of oxygen therapy and respiratory support practices among hospitals in the African Neonatal Network

John Baptist Nkuranga
Brandon R. Hadfield
Jocelyne Bukeyeneza
Emmanuel Bizimana
Olufunke Bolaji
Erika M. Edwards
Pamela Henderson
Melissa Muparamoto
Benenia Muzuva
Misrak Tadesse
Redeat Workneh Tadesse
Gemechis Wari
Alexander G. Stevenson
Dan Lutasingwa
Danielle E. Y. Ehret

https://dx.doi.org/10.4314/jan.v3i3.8

Received: 1st July 2025
Accepted: 7th July 2025

John Baptist Nkuranga (✉)
Emmanuel Bizimana
Jocelyne Bukeyeneza
University of Rwanda/African Health Sciences University, Kigali, Rwanda
Email: nkuranga.baptist@gmail.com

Brandon R. Hadfield
Rwanda Military Hospital, Kigali, Rwanda

Pamela Henderson
Alexander G. Stevenson
African Neonatal Association, Kigali, Rwanda and Harare, Zimbabwe

Olufunke Bolaji
Federal Teaching Hospital, Ido-Ekiti, Nigeria

Erika M. Edwards
Danielle E. Y. Ehret
Vermont Oxford Network and University of Vermont, Burlington, Vermont, USA

Melissa Muparamoto
Benenia Muzuva
Mbuya Nehanda Maternity Hospital, Harare, Zimbabwe

Abstract: *Background:* Neonatal respiratory support, including oxygen therapy, is critical for reducing neonatal mortality in sub-Saharan Africa, where neonatal outcomes remain poor due to infrastructure and resource limitations.
Methods: Fourteen hospitals in the African Neonatal Network responded to an annual facility survey and a health facility survey co-developed by faculty in the African Neonatal Network and Vermont Oxford Network. All analyses use descriptive statistics.
Results: While oxygen was universally available, only 78% of hospitals had pulse oximeters and 21% had blood gas analysis capabilities. CPAP was available in 77% of hospitals, but only 36% had surfactant and 14% offered blended oxygen to all neonates. Protocols for oxygen use varied, with just 64% having target saturation guidelines and 43% using pulse oximeter alarms. Oxygen supply interruptions were common, and equipment gaps, like compressed air and monitoring tools, were prevalent.
Conclusion: Major deficiencies in neonatal respiratory care and oxygen use persist across ANN hospitals, including limited access to monitoring tools, standardized protocols, and advanced therapies. Addressing these gaps through infrastructure investments, protocol development and standardization, training, and supply chain improvements is essential to advancing neonatal care through optimal respiratory support in resource-limited African settings.

Keywords: Neonatal care; Oxygen therapy; Respiratory support; Continuous Positive Airway Pressure (CPAP); Neonatal mortality; Pulse oximetry; Surfactant therapy; Resource-limited settings.

Résumé: *Contexte:* Le soutien respiratoire néonatal, y compris l'oxygénothérapie, estessentiel pour réduire la mortalité néonatale en Afrique subsaharienne, où les resultants restent mediocre en raison des limites en matière d'infrastructures et de ressources.
Méthodes: Quatorze hôpitaux du Réseau Néonatal Africain ont répondu à une enquête annuelle sur les établissements et à une enquête sur les structures de santé, co-développées par des membres du Réseau Néonatal Africain et du Vermont Oxford Network. Toutes les analyses ont été réalisées à l'aide de statistiques descriptives.
Résultats: Bien que l'oxygène soit disponible dans tous les hôpitaux, seuls 78% disposaient d'oxymètres de pouls et 21% avaient accès à l'analyse des gaz

Misrak Tadesse
Vermont Oxford Network and Johns Hopkins School of Medicine, Baltimore, Maryland, USA

Redeat Workneh Tadesse
Gemechis Wari
St. Paul's Millenium Medical College, Addis Ababa, Ethiopia

Dan Lutasingwa
Health Development Initiative
Kigali, Rwanda

sanguins. La CPAP était disponible dans 77 % des hôpitaux, mais-seulement 36% avaientaccès au surfactant et 14 % proposaient un mélange d'oxygène à tous les nouveau-nés. Les protocols d'utilisation de l'oxygèn evariaient : 64 % seulement des hôpitaux disposaient de directives sur les saturations cibles, et 43 % utilisaient les alarmes des oxymètres de pouls. Les interruptions d'approvisionnement en oxygène étaient fréquentes, et des lacunes important esétaient observes en matière d'équipements, notamment l'air comprimé et les outils de surveillance.

Conclusion: De graves insuffisances persistent dans la prise en charge respiratoire néonatale et l'utilisation de l'oxygène dans les hôpitaux du Réseau Néonatal Africain, notamment en ce qui concerne l'accès limité aux outils de surveillance, aux protocols standardisés et aux traitement savancés. Combler ces lacunes par des investissements dans les infrastructures, le développement et la standardisation des protocoles, la formation, et l'amélioration de la chaîne d'approvisionnement est indispensable pour faire progresser les soins néonatals grâce à un soutien respiratoire optimal dans les contexts africains à ressources limitées.

Introduction

Neonatal care is an essential component of healthcare, particularly in sub-Saharan Africa where neonatal mortality remains a significant public health concern.[1] Despite advances in medical technology and neonatal care practices globally, neonatal morbidity and mortality rates remain high in many low- and middle-income countries (LMICs).[2] Neonatal mortality accounted for nearly 40% of all under-five deaths globally, with most of these deaths occurring in LMICs.[3] In sub-Saharan Africa, specifically, the neonatal mortality rate is among the highest in the world, exacerbated by factors such as inadequate access to well-trained health care professionals, insufficient medical infrastructure, and limited availability of essential medical resources.[4,5]

Neonatal care in Africa is characterized by significant variability in resource availability and clinical practices across countries and healthcare settings. While some countries in Africa have made notable progress in reducing neonatal mortality rates through targeted interventions, many still struggle with basic infrastructure and medical supplies, particularly in rural or underserved regions.[6] The availability of reliable oxygen and the tools to monitor and adjust oxygen levels, a fundamental intervention for managing neonatal respiratory distress syndrome (RDS), apnoea of prematurity, and other respiratory conditions, is often limited by both financial and technical barriers.[7] This lack of access to essential neonatal respiratory support modalities contributes to poor outcomes for newborns requiring critical care.[8]

Several studies across Africa have highlighted the need for improved neonatal care infrastructure. A study in Kenya found that less than half of neonatal units had access to continuous positive airway pressure (CPAP) machines, and only a fraction had access to neonatal ventilators.[9] Similarly, a study in Uganda highlighted that neonatal oxygen therapy protocols were not consistently followed, with substantial variation in how oxygen was delivered, and significant gaps in the availability of trained personnel to administer these treatments.[10] These findings are mirrored in other African countries, where inconsistencies in the availability of essential neonatal services continue to challenge the effectiveness of neonatal care.[11]

The African Neonatal Association and Vermont Oxford Network partnered to co-develop the African Neonatal Network (ANN), a collaborative quality improvement (QI), learning and leadership development community. The ANN launched in 2023 across 17 neonatal units in five countries, Ethiopia, Nigeria, Rwanda, Uganda and Zimbabwe. The network seeks to improve the quality of care through promoting a networked and collaborative approach, where hospitals can share resources, data, and strategies for improving the quality of neonatal care. Through collaborative efforts, the ANN aims to standardize neonatal care practices, share expertise and benchmark to global standards to improve access to life-saving interventions like oxygen therapy. This network supports the establishment of guidelines, protocols and adoption of best practices, which have been shown to improve outcomes in resource-limited settings[12]

Despite the need to standardize neonatal oxygen therapy across members of the ANN, there are no recently published papers on the current practices to serve as a baseline to inform future quality improvement projects. The purpose of this evaluation was to determine the current status of oxygen use and respiratory support infrastructure critical to neonatal care across the network.

Methods

Data collection was conducted in 14 African Neonatal Network (ANN) member hospitals across five countries: Ethiopia, Nigeria, Rwanda, Uganda, and Zimbabwe.

Vermont Oxford Network (VON) conducts an annual survey for members that was co-developed with ANN faculty members, which includes information on the hospital setting, number of beds and admissions, staffing, obstetric service, follow-up clinic, resuscitation and essential newborn care, transfers and transport, family-centred care, services provided by the neonatal unit, guidelines in the neonatal unit, quality assurance/ continuous quality improvement, and level of neonatal care. Participation in the membership survey is mandatory. The responses used for this manuscript are from 2023.

In October 2023, the ANN conducted a health facility assessment to collect more detailed information on buildings and facilities, medications, diagnostics and consumables, equipment, staffing, governance, thermal regulation and foetal transition, nutrition, family-centred care and kangaroo mother care, infection prevention and control, and perceived priorities. Tables of hospital-level measures include data from both the membership survey and the health facility assessment.

Tables of hospital-level measures include data from both the membership survey and the health facility assessment. All analyses are descriptive.

The collaborative QI project and subsequent assessments received individual and hospital institutional research and ethics review approvals at the start of the collaborative and learning initiative.

Results

All hospitals reported that oxygen is available, although only 78% reported having oximeters and only 21% reported having blood gas analysis (Table 1). Ten hospitals (77%) reported having nasal CPAP with blended oxygen and seven (54%) had CPAP with 100% oxygen. Surfactant was reported available at five hospitals (36%). ROP screening was done in eight hospitals (57%), and retinal cryotherapy or laser retinal ablation treatment was available at four hospitals (28%).

Among the member hospitals, 86% had guidelines for oxygen and CPAP initiation, escalation, and wearing that were used consistently while 64% had protocols on target saturations for neonates on oxygen and 43% had policies on pulse oximeter alarms.

Of the 14 hospitals, six (43%) reported rarely or never having an interruption in oxygen supply, while five (36%) reported rarely or never having an interruption in compressed air of more than three minutes (Table 2). Seven hospitals (50%) reported not having compressed air.

Blended air-oxygen was not available at 29% of hospitals, while 57% of hospitals reported having blended air-oxygen for some infants and 14% reported having blended air-oxygen for every infant, including in the labor ward, operating theatre, and neonatal unit. Fifty percent of the hospitals reported having air compressors with the ability to blend air-oxygen.

Table 1: Availability of oxygen and related items at 14 African Neonatal Network Hospitals

	No.	%
Surveyed facilities	14	100
Source of Oxygen		
Piped*	6	43
Cylinder*	9	64
Concentrator*	5	36
Presence of:		
Pulse oximetry	11	79
Continuous pulse oximetry for patients on CPAP	8	62
Nasal CPAP with 100% oxygen**	7	54
Nasal CPAP with blended oxygen**	10	77
Intubation equipment**	10	77
Trained intubation team**	9	69
Pneumothorax treatment team	5	36
Mechanical ventilation	8	57
Blood gas analysis	3	21
Surfactant	5	36
Caffeine	6	43
Aminophylline	9	64
Indirect ophthalmoscopy ROP screening	8	57
Retinal cryotherapy or laser ablation treatment	4	29

*Could answer "yes" to more than 1
**N=13

Table 2: Interruptions in oxygen supply at 14 African Neonatal Network Hospitals

	No.	%
Interruption in Oxygen Supply of >3 Minutes		
At least once a month	5	36
At least once a year	3	21
Rarely or never	6	43
Interruption in Compressed Air of >3 Minutes		
At least once a month	1	7
At least once a year	1	7
Rarely or never	5	36
Not applicable	7	50
Not Enough Oxygen Sources for Every Infant		
At least once a month	2	14
At least once a year	2	14
Rarely or never	10	71

Discussion

The ANN surveys found that critical aspects of neonatal respiratory care, such as blood gas analysis and the availability of surfactant therapy, remain limited. These findings highlight a gap in the availability of comprehensive respiratory care for neonates, which is crucial for improving outcomes.[11,12]

Most ANN member hospitals (64%) had protocols on target saturations for neonates on oxygen while the rest

lacked these protocols which guide ideal neonatal oxygen therapy. However, the reliance on various oxygen sources – piped systems (43%), cylinders (64%), and concentrators (36%) – highlight infrastructural variability. This finding contrasts with high-income countries (HICs), where piped oxygen and medical air are standard in most neonatal units, ensuring consistent and uninterrupted supply.[14] The lack of uniformity in oxygen delivery methods in surveyed hospitals may reflect challenges in infrastructure development and resource allocation in low- and middle-income countries (LMICs).[16] In the ANN, where 47.7% of all infants discharged in 2024, and 61.0% of those born less than 32 weeks' gestation, were exposed to oxygen, both delivery and supply are critical issues.[17]

Only 79% of hospitals had pulse oximeters, and fewer (62%) employed continuous pulse oximetry for neonates on CPAP. These figures reveal a gap in routine monitoring compared to HICs, where pulse oximetry is considered a cornerstone for neonatal respiratory management.[18] Without regular or continuous pulse oximetry, adjusting oxygen levels to maximise outcomes and avoid oxygen toxicity is nearly impossible. The absence of blood gas analysis in most facilities (79%) severely limits the ability to monitor respiratory status comprehensively, impeding optimal clinical decision-making.[19]

Surfactant was available in only 36% of hospitals. HICs routinely administer surfactant therapy as a standard of care for neonates with respiratory distress syndrome (RDS) who meet treatment criteria, significantly improving survival rates.[20] Among infants born less than 32 weeks' gestation discharged from ANN member hospitals in 2024, 9.8% received surfactant.[17]

Similarly, the limited availability of blended oxygen raises concerns, as administering unblended oxygen is associated with risks of hyperoxia and retinopathy of prematurity (ROP).[21] Of infants born less than 32 weeks' gestation discharged from ANN member hospitals in 2024, 12.1% received an ROP examination and 59.6% of those had ROP.[17] These findings emphasize the need for investments in equipment that enable precise oxygen delivery and enhance safer oxygen therapy use among ANN neonatal units to prevent ROP.[22]

While 86% of hospitals reported having guidelines for oxygen and CPAP use, only 64% had protocols for target oxygen saturations. Furthermore, half of the hospitals lacked policies on pulse oximeter alarms, which are critical for timely detection of desaturation or hyperoxia.[23] These deficiencies may result in inconsistent care practices, potentially leading to preventable complications, highlighting the need for standardized protocols.[24]

Intermittent interruptions in oxygen supply were common, with only 43% of hospitals reporting rare or no interruptions. This finding contrasts with hospitals in HICs, where oxygen supply is rarely disrupted due to robust infrastructure and maintenance. Addressing these supply chain vulnerabilities is crucial for ensuring reliable neonatal respiratory care.[25] Because of the devastating effects in multiple babies should oxygen supply be interrupted for more than a few minutes, it seems logical that ensuring a consistent, reliable supply of oxygen should be high in the priorities of investing in neonatal care infrastructure.

Although 69% of hospitals reported having trained intubation teams, the limited availability of pneumothorax treatment teams (36%) points to skill gaps. Investing in training programs and simulation-based education could enhance the capacity of healthcare providers to manage critical neonatal conditions.[26]

The findings from the ANN align with challenges observed in many LMICs, where respiratory care is significantly constrained by limited resources, training, and inconsistency.[27] Efforts in South-East Asia and Latin America to improve neonatal care through initiatives such as CPAP scale-up and oxygen monitoring have demonstrated mortality reductions of up to 40%,[28] suggesting that similar investments could yield substantial benefits in Africa. Quality improvement can also play a role. In the Ethiopian Neonatal Network, teams participating in a quality improvement collaborative used remote education and mentorship, without additional resources, to improve documentation of the Downes score on admission, increase the number of infants receiving CPAP, and decrease mortality.[29]

LMICs, including Rwanda and other African nations, face challenges in aligning neonatal care standards with global benchmarks. For instance, studies in sub-Saharan Africa report similar deficits in respiratory care infrastructure and human resource availability.[30,31] However, innovative solutions such as solar-powered oxygen concentrators and task-shifting strategies have shown promise in improving neonatal outcomes in resource-constrained settings.[32]

The strengths of this evaluation centre on reporting the status of oxygen use and respiratory support infrastructure in the pilot ANN units at the launch of the network; a benchmark critical to establish prior to prioritizing network improvement efforts. Although the quantitative findings from the ANN may not be generalizable to the broad sub-Saharan African context or LMICs globally, they may have comparative value and encourage assessment of these important infrastructure elements in other contexts. This evaluation is cross-sectional, and indeed there is hope that the results will change over time with repeated measurement following advocacy and investments directed toward improving the gaps identified. This evaluation, however, does have important limitations that deserve highlighting. The survey is self-reported by neonatal team leaders, without confirming answers or functionality on a site visit. The answers reflect a snapshot of time as answers are often dynamic. Although honest answers are highly encouraged for all

of ANN work, it is possible that some survey respondents may err on the side of projecting a positive picture when resources are in flux. These limitations underscore the importance of the gaps identified, noting that the magnitudes could potentially be even larger at times, and in different contexts.

Conclusion

The survey highlights significant gaps in respiratory care services across neonatal units in the African Neonatal Network. Although oxygen is universally available, inconsistencies in equipment, protocols, and training limit the quality of care. Addressing these challenges requires a multifaceted approach:

- Infrastructure Investments: Prioritizing piped oxygen systems, blended air-oxygen delivery devices, and critical monitoring equipment like pulse oximeters and blood gas analysers.
- Standardization of Care: Developing and enforcing consistent guidelines for oxygen therapy, target saturation levels, and alarm settings for pulse oximeters.
- Capacity Building: Expanding training programs to equip neonatal teams with skills for advanced respiratory support and emergency procedures.
- Sustainable Solutions: Strengthening supply chains to ensure uninterrupted oxygen delivery and exploring cost-effective technologies for resource-limited settings.

These efforts are essential to bridging the gap between neonatal respiratory care in LMICs and HICs, ultimately reducing neonatal morbidity and mortality in Africa.

Acknowledgments

We are indebted to our colleagues at the following hospitals who submit data to VON on behalf of infants and their families: St. Paul's Millennium Medical College, Addis Ababa, Ethiopia; Tikur Anbessa Specialized Hospital, Addis Ababa, Ethiopia; Tirunesh Beijing Hospital, Addis Ababa, Ethiopia; Assosa Hospital, Asosa, Ethiopia; Hawassa Referral Hospital, Awassa, Ethiopia; Ayder Hospital, Mekelle, Ethiopia; Sacred Heart Hospital, Abeokuta, Nigeria; Federal Teaching Hospital Ido-Ekiti, Ekiti, Nigeria; King Faisal Hospital, Kigali, Rwanda; Mengo Teaching Hospital, Kampala, Uganda; St Francis Nsambya Hospital, Kampala, Uganda; Lubaga Hospital, Kampala, Uganda; Murambinda Mission Hospital, Harare, Zimbabwe; Neocare Baby Hospital, Harare, Zimbabwe.

Funding: Bill and Melinda Gates Foundation
INV-042791

References

1. World Health Organization. Newborn mortality [Internet]. 2024. Available from: https://www.who.int/news-room/fact sheets/detail/newborn-mortality
2. Steenhoff AP, Coffin SE, Kc A, Nakstad B. Editorial: Neonatal health in low- and middle-income countries. Now is the time. *Front Pediatr. 2023 Apr 13;11:1168915.*
3. UNICEF. Neonatal mortality [Internet]. 2025. Available from: https://data.unicef.org/topic/child-survival/neonatal-mortality/.
4. Nkundabaza C, Rukundo G, Sinayobye J d'A, Ntaganira J, Mukamurigo J. Neonatal mortality and associated factors at a provincial hospital, Western Province of Rwanda: A facility based cross-sectional study, *2019-2021. JIEPH. 2024;7 (3):3.*
5. Liu L, Oza S, Hogan D, et al. Global, regional, and national causes of under-5 mortality in 2000-15: an updated systematic analysis with implications for the Sustainable Development Goals. *Lancet. 2016;388 (10063):3027-3035.*
6. Zaidi AKM, Darmstadt GL, Stoll BJ. Neonatal infections: a global perspective. In: Wilson CB, Nizet V, Maldonado Y, Remington JS, Klein JO, editors. *Remington and Klein's Infectious Diseases of the Fetus and Newborn Infant, 8th ed. Saunders; 2015.*
7. Ekhaguere OA, Okonkwo IR, Batra M, Hedstrom AB. Respiratory distress syndrome management in resource limited settings-Current evidence and opportunities in 2022. *Front Pediatr. 2022;10: 961509.*
8. Lategan I, Price C, Rhoda NR, Zar HJ, Tooke L. Respiratory Interventions for Preterm Infants in LMICs: A Prospective Study From Cape Town, South Africa. *Front Glob Womens Health. 2022;3:817817.*
9. Kakibibi P, Marangu-Boore D, Murila F. Missed opportunity for nasal continuous positive airway pressure in preterm neonates admitted at a tertiary-level hospital newborn unit in Kenya: a mixed method study. *BMJ Open. 2025;15(1):e085026*
10. Graham HR, Kamuntu Y, Miller J, et al. Hypoxaemia prevalence and management among children and adults presenting to primary care facilities in Uganda: A prospective cohort study. *PLoS Glob Public Health. 2022;2 (4):e0000352.*

11. Bee M, Shiroor A, Hill Z. Neonatal care practices in sub -Saharan Africa: a systematic review of quantitative and qualitative data. *J Health PopulNutr. 2018;37(1):9.*
12. Hansen A, Magge H, Labrecque M, et al. The development and implementation of a newborn medicine program in a resource-limited setting. *Public Health Action. 2015;5 (1):17-22.*
13. Morgan MC, Maina B, Waiyego M, et al. Pulse oximetry values of neonates admitted for care and receiving routine oxygen therapy at a resource-limited hospital in Kenya. *J Paediatr Child Health. 2018;54(3):260-266.*
14. Sodero S, Dhungana N, Sandoe F. Vital mobilities of medical oxygen: Theorising oxygen justice. *Soc Sci Med. 2025;364:117464.*
15. Bhatt N, Nepal S, Pinder RJ, Lucero-Prisno DE, Budhathoki SS. Challenges of hospital oxygen management during the COVID-19 pandemic in rural Nepal. *Am J Trop Med Hyg. 2022;106 (4):997-999.*
17. Stevenson AG, Abayneh M, Bolaji O, et al. Characteristics, interventions, and status of infants discharged from 14 hospitals in the African Neonatal Network, 2024. *J Afric Neonatol. 2025;3(3): 68-77.*
18. Al-Beltagi M, Saeed NK, Bediwy AS, Elbeltagi R. Pulse oximetry in pediatric care: Balancing advantages and limitations. *World J Clin Pediatr. 2024;13(3):96950.*
19. Castro D, Patil SM, Zubair M, Keenaghan M. Arterial blood gas. In: StatPearls. StatPearls Publishing, 2024.
20. Banerjee S, Fernandez R, Fox GF, et al. Surfactant replacement therapy for respiratory distress syndrome in preterm infants: United Kingdom national consensus. *Pediatr Res. 2019;86(1):12-14.*
21. Aggarwal V, Bhatia R, Tan K. Oxygen saturation levels and retinopathy of prematurity in extremely preterm infants - a case control study. *BMC Pediatr. 2023;23 (1):449.*
22. Gilbert C, Malik ANJ, Nahar N, et al. Epidemiology of ROP update - Africa is the new frontier. *Sem Perinatol. 2019;43(6):317-322.*
23. Pretto JJ, Roebuck T, Beckert L, Hamilton G. Clinical use of pulse oximetry: official guidelines from the Thoracic Society of Australia and New Zealand. *Respirology. 2014;19(1):38-46.*
24. Graham HR, King C, Rahman AE, et al. Reducing global inequities in medical oxygen access: the Lancet Global Health Commission on medical oxygen security. *Lancet Glob Health. 2025;13 (3):e528-e584.*
25. Smith V, Changoor A, McDonald C, et al. A comprehensive approach to medical oxygen ecosystem building: an implementation case study in Kenya, Rwanda, and Ethiopia. *Glob Health Sci Pract. 2022;10(6):e2100781.*
26. Pong KM, Teo JT, Cheah FC. Simulation-based education in the training of newborn care providers-A Malaysian Perspective. *Front Pediatr. 2021;9:619035.*
27. Inglis R, Ayebale E, Schultz MJ. Optimizing respiratory management in resource-limited settings. *Curr Opin Crit Care. 2019;25(1):45-53.*
28. Thukral A, Sankar MJ, Chandrasekaran A, Agarwal R, Paul VK. Efficacy and safety of CPAP in low- and middle-income countries. *J Perinatol. 2016;36(Suppl 1):S21-S28.*
29. Ehret DEY, Worku B, Demtse A, et al. Remote mentorship to improve continuous positive airway pressure use in the Ethiopian Neonatal Network. *Pediatr. 2025; 156(1):e2024067985.*
30. Erhabor GE. Respiratory health in Africa: strides and challenges. *JPATS. 2021;2 (1):11-17.*
31. Sheffel A, Andrews KG, Conner R, et al. Human resource challenges in health systems: evidence from 10 African countries. *Health Policy Plan. 2024;39(7):693 -709.*
32. Conradi N, Claude KM, Lee BE, Saleh A, Mandhane P, Hawkes M. Utility of solar-powered oxygen delivery in a resource-constrained setting. *Pulmonology. 2023;29 (4):315-322.*