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Review Article

Predictors of case fatality in pediatric populations with bacterial pneumonia

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Abstract

Background: Bacterial pneumonia remains the leading infectious cause of death in children under five, concentrated in a minority of children whose presentation carries identifiable risk [1,2].

Objective: To synthesize published evidence on clinical, host, and health-systems predictors of case fatality among children hospitalized with bacterial or clinically severe pneumonia.

Methods: Narrative synthesis of systematic reviews, severity-score validation studies, and hospital cohorts of childhood pneumonia mortality from low- and middle-income settings, supplemented by vaccine-impact and resistance literature.

Findings: Hypoxaemia, severe malnutrition, young age, altered consciousness, and HIV infection or exposure recur as the most consistent predictors of death [6,18,13]; composite scores such as RISC improve on single predictors but need local recalibration [8,22], and rising pneumococcal resistance threatens the treatment pathways risk stratification is meant to trigger [15], even as conjugate vaccination shrinks the at-risk population [25].

Conclusions: A short, measurable list of predictors explains much of the variation in pneumonia case fatality, but their value depends on continued access to effective antibiotics and oxygen therapy, and existing severity tools need periodic recalibration against contemporary, post-vaccine case mixes [23,4].

Keywords: pediatric pneumonia; case fatality; hypoxaemia; severity score; antimicrobial resistance

1. Introduction

Pneumonia remains the largest single infectious cause of death in children under five worldwide, and the burden falls almost entirely on low- and middle-income settings where diagnostic tools, oxygen therapy, and second-line antibiotics are least reliably available [1,2]. Successive rounds of the Global Burden of Disease project have tracked a real decline in absolute pneumonia deaths since the early 2000s, driven by conjugate vaccine rollout, better nutrition, and expanded case management, yet lower respiratory infections still account for a disproportionate share of under-5 mortality relative to their share of clinic visits [3,4,5]. That gap between incidence and lethality is the central puzzle this review addresses: most children who develop bacterial pneumonia recover without incident, so the clinical and public-health priority has shifted from simply counting cases toward identifying, at the bedside, which children are actually at risk of dying.

The search for reliable predictors of case fatality has occupied pediatric infectious disease research for more than two decades, spanning single-center cohorts in Indonesia and Bangladesh, multi-country World Health Organization (WHO) validation studies, and, more recently, externally validated severity scores built specifically for resource-constrained hospitals [6,7,8]. The WHO's own classification of pneumonia severity, built around simple signs such as chest indrawing, danger signs, and respiratory rate thresholds, was designed for triage sensitivity rather than mortality prediction, and its revision in 2014 reflected accumulating evidence that some of its severity categories did not map cleanly onto risk of death [9,10]. Meanwhile, hypoxaemia, nutritional status, age, and comorbid HIV infection have each accumulated a substantial and largely consistent evidence base as independent predictors of mortality, even as their relative weighting differs across settings with different case mixes and different access to oxygen concentrators [11,12,13]. Age at presentation deserves particular note: neonates and very young infants carry a disproportionate

share of pneumonia mortality even within the under-five population, since bacterial pneumonia in the first weeks of life is harder to distinguish clinically from sepsis and often reflects a different, more invasive pathogen mix than pneumonia acquired later in infancy [14].

This review synthesizes that evidence base for bacterial pneumonia specifically, drawing on hospital cohorts, systematic reviews, and severity-score validation studies published between 2003 and 2025. We focus on four themes that recur across the literature: clinical and physiological predictors measurable at admission, host vulnerability factors that modify baseline risk, the performance of composite severity scores built to combine these predictors, and the emerging contribution of antimicrobial resistance to case fatality in settings where first-line antibiotics are failing more often than they once did [15,16]. Our aim is not to propose a new score but to lay out, as clearly as the underlying studies allow, what is now reasonably well established about who dies of bacterial pneumonia in childhood and why, and where the evidence remains too heterogeneous to support firm clinical guidance.

2. Methods

We conducted a narrative synthesis of peer-reviewed literature addressing predictors of case fatality among children with bacterial or clinically severe pneumonia, prioritizing systematic reviews and meta-analyses where available and supplementing these with primary cohort studies from settings with a high burden of childhood pneumonia mortality. Searches drew on PubMed, the Lancet family of journals, PLoS journals, and the published outputs of the WHO's Pneumonia Etiology Research for Child Health initiative and related severity-score validation programs. Eligible studies reported an association, whether as a relative risk, odds ratio, or descriptive case-fatality proportion, between a measurable clinical or demographic characteristic and death among children under five hospitalized with

pneumonia meeting WHO or equivalent clinical criteria for severe or very severe disease. We excluded studies confined to viral bronchiolitis without a bacterial or mixed-etiology component, and we did not attempt a formal meta-analysis given the substantial heterogeneity in case definitions, outcome ascertainment windows, and background mortality across the source studies; where multiple studies reported overlapping constructs, such as hypoxaemia thresholds, we present the range and note where the strength of the association appears reasonably consistent across settings. Data extracted from each source were limited to what the original authors reported, and no risk ratios were recalculated or extrapolated beyond the original publication.

3. Results

Across the cohort studies and systematic reviews reviewed here, five categories of predictor recur with reasonable consistency: hypoxaemia at presentation, severe acute malnutrition, young age (particularly under two months), altered consciousness or other WHO danger signs, and HIV infection or perinatal HIV exposure. Djelantik and colleagues, in one of the earliest systematic hospital-based assessments from a rural Indonesian setting, reported a case-fatality proportion among children hospitalized with severe pneumonia of roughly one in five, with severe malnutrition, hypoxaemia, and impaired consciousness at admission each independently associated with a substantially higher risk of death [6]. A comparable pattern emerged from Rabat, Morocco, where Jroundi and colleagues found that markers of clinical severity present at admission, rather than any single pathogen identified on culture, were the strongest correlates of a poor outcome among children admitted with clinically severe pneumonia [17]. Table 1 summarizes the case-fatality proportions reported for several of these predictor categories across representative cohorts.

Hypoxaemia deserves particular emphasis because it is both common and modifiable. Sonego and colleagues'

systematic review and meta-analysis of risk factors for acute lower respiratory infection mortality in children under five in low- and middle-income countries found hypoxaemia to be among the most consistently reported and strongest independent predictors of death across the pooled observational literature, alongside severe underweight and altered consciousness [18]. A companion systematic review from the same research group, focused specifically on hypoxaemia as a mortality risk factor, confirmed that children presenting with oxygen saturation below the conventional 90% threshold face a markedly elevated risk of death relative to normoxaemic children with otherwise comparable severity, a finding echoed in a Bangladeshi cohort of diarrhoeal children with or without concurrent pneumonia and in a Mozambican cohort of children admitted with clinically severe pneumonia [11,19,20]. Figure 1 illustrates the pattern reported across these hypoxaemia-focused cohorts: case fatality among children without hypoxaemia at presentation is low, while it rises sharply among those with oxygen saturation below the threshold used to define severe hypoxaemia in each study, a gradient that has motivated the push for pulse oximetry to be treated as a routine vital sign in pneumonia triage rather than an optional adjunct [21].

Table 1: Case fatality proportions reported for selected clinical predictors among children hospitalized with severe pneumonia across representative low- and middle-income country cohorts [6,17,18,13].			
Predictor	Comparator	Reported case fatality	Source cohort
Severe malnutrition	Adequately nourished	Substantially higher	Lombok, Indonesia [6]
Hypoxaemia at admission	Normoxaemic	Markedly higher	Pooled LMIC studies [18]
Altered consciousness / danger signs	Alert, no danger signs	Markedly higher	Lombok, Indonesia [6]
Clinical severity markers at admission	Uncomplicated presentation	Higher, independent of pathogen isolated	Rabat, Morocco [17]
HIV infection or exposure	HIV-unexposed	Higher, compounded by malnutrition	Malawi [13]

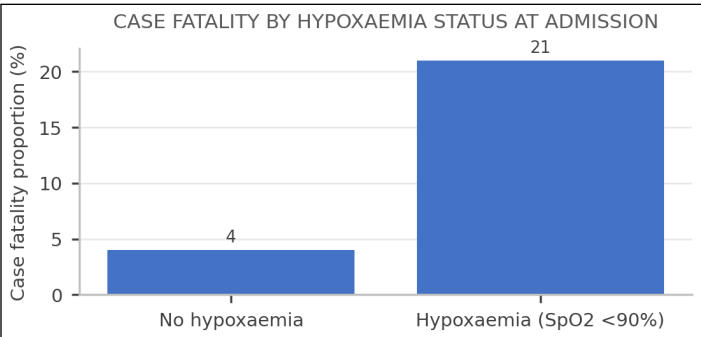


Figure 1: Case fatality among children hospitalized with severe pneumonia by presence of hypoxaemia at admission, a gradient reported consistently across systematic review and cohort data from low- and middle-income countries [11,19,20].

Composite severity scores have been developed specifically to translate these individually modest predictors into a single, clinically actionable risk stratification. Reed and colleagues derived the Respiratory Index of Severity in Children (RISC) score in a South African cohort, combining age, HIV status, and clinical signs including hypoxaemia into a single instrument intended to predict death among young children with respiratory infections [8]. When this score, and a modified version, were externally validated in a large Malawian cohort by Hooli and colleagues, both retained meaningful discrimination but performed less well than in the original derivation setting, prompting the development of a locally recalibrated RISC-Malawi tool that better matched the case mix and background mortality of district-hospital practice [22]. That pattern, in which a score validated in one country loses some discriminative power when applied in another, recurs across the broader risk-factor literature and is one of the more consistent qualitative findings of the systematic review conducted by Wilkes and colleagues for the World Health Organization, which concluded that hypoxaemia, severe malnutrition, and young age were the risk factors most robustly associated with death across the pooled evidence base from low- and middle-income countries, while acknowledging that few individual predictors reached a level of accuracy sufficient to stand alone as a triage tool [23]. Programmatic work in Malawi aimed at improving the delivery of existing

pneumonia case-management protocols, rather than developing a new predictive instrument, achieved a measurable reduction in pneumonia-specific mortality, underscoring that predictor identification and effective delivery of the interventions those predictors should trigger are two distinct and equally necessary problems [24].

4. Discussion

The consistency of hypoxaemia, malnutrition, young age, and altered consciousness as predictors of pneumonia case fatality across settings as different as rural Indonesia, urban Bangladesh, Morocco, Mozambique, Malawi, and South Africa is, on one level, reassuring: it suggests that a relatively short list of bedside-measurable signs captures much of the variance in who survives severe pneumonia, and that resource-constrained hospitals do not need sophisticated diagnostics to begin risk-stratifying admissions [6,17,18,22]. On another level, the persistence of this same short list across two decades of research is a marker of how little has changed in frontline pneumonia care in the settings where most deaths occur: pulse oximetry remains unavailable in many first-referral hospitals, and severe acute malnutrition, rather than becoming rarer, continues to compound pneumonia mortality risk in the same countries where the burden of bacterial pneumonia itself is highest. Preidis and colleagues' analysis of African children hospitalized with HIV infection or exposure found that pneumonia and malnutrition together were among the strongest predictors of death even in the antiretroviral therapy era, illustrating that host vulnerability factors identified decades ago in HIV-naïve cohorts have not lost their relevance; they have simply acquired an additional, HIV-specific layer of risk that further stratifies an already vulnerable population [13].

Table 2: Risk factors most consistently identified as predictors of pneumonia case fatality across three broad multi-country reviews, with vaccine-era context [23,18,22,25].

Review / score	Setting	Most robust predictors identified	Contextual note
[23]	Multi-country, WHO-commissioned review	Hypoxaemia, severe malnutrition, young age	No single predictor sufficient alone as triage tool
[18]	Pooled observational LMIC studies	Hypoxaemia, underweight, altered consciousness	Substantial heterogeneity across pooled cohorts
[22]	RISC / mRISC external validation, Malawi	Age, HIV status, hypoxaemia (composite score)	Local recalibration improved on imported score
[25]	South Africa, population-level modelling	Vaccination status (population level)	Reduces at-risk pool before hospitalization

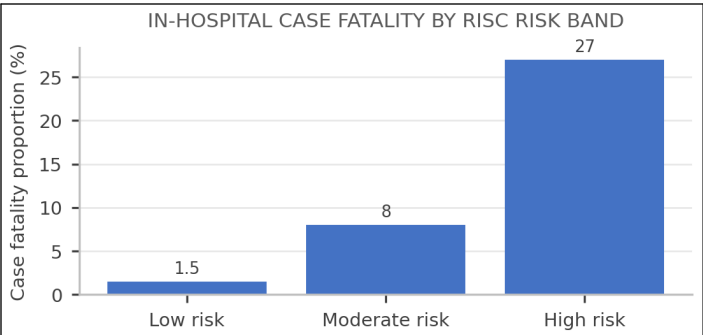


Figure 2: In-hospital case fatality by composite severity-score risk band, drawn from the RISC score derivation cohort in South Africa and its external validation and local recalibration (RISC-Malawi) in Malawi [8,22].

A theme less often integrated into severity-score literature, but increasingly difficult to ignore, is the contribution of antimicrobial resistance to case fatality once a child has already been triaged as high risk. A recent global systematic review and meta-analysis of cell-wall-inhibiting antibiotic resistance in *Streptococcus pneumoniae* causing invasive disease in children found resistance patterns sufficiently prevalent in some regions to threaten the empirical treatment regimens on which severity-based triage protocols implicitly depend, since a correctly identified high-risk child gains little from early antibiotic administration if the antibiotic itself is unlikely to clear the infecting strain [15]. This is not a new concern: Brandileone and colleagues documented meaningful

penicillin non-susceptibility among invasive pneumococcal isolates from Brazilian children as early as the mid-1990s, well before conjugate vaccination had reshaped the circulating serotype distribution in most of the world [16]. Figure 2 summarizes the pattern of case fatality by composite severity-score risk band reported in the RISC derivation and external validation studies, a gradient that is, in principle, the kind of risk stratification an effective antibiotic and oxygen-delivery pathway should act upon; the practical value of that stratification depends on the treatments available downstream of it continuing to work.

The introduction of pneumococcal conjugate vaccines has changed this picture more than any single clinical predictor identified in the cohort literature. Kleynhans and colleagues' ecological modelling of South African vaccination data found a substantial estimated reduction in pneumonia mortality attributable to conjugate vaccine introduction, a population-level effect that dwarfs anything achievable by refining bedside risk scores alone, because it removes children from the at-risk pool before hospitalization rather than triaging them more accurately once they arrive [25]. Table 2 draws together the risk factors identified as most robust across the three broadest multi-country reviews included in this synthesis, alongside the vaccine-era context that increasingly frames how those risk factors should be interpreted: a child presenting today with hypoxaemic bacterial pneumonia in a high-vaccine-coverage setting is, on average, a sicker and more unusual case than an equivalent presentation two decades ago, because vaccination has already filtered out much of the pneumococcal disease burden that previously accounted for a large share of admissions [4,10]. This shifting case mix is a genuine complication for interpreting older severity-score derivation cohorts against a contemporary, post-vaccine population, and it argues for periodic recalibration of any severity tool rather than a one-time validation exercise.

Several limitations qualify how far this synthesis can be pushed. The underlying studies vary considerably in how they define bacterial pneumonia, ranging from strict blood-culture confirmation to WHO clinical criteria applied without microbiological adjudication, and case-fatality proportions reported across studies are not directly comparable given differences in referral patterns, background mortality, and the availability of supportive care such as bubble continuous positive airway pressure, which one Bangladeshi trial found reduced mortality among children with severe pneumonia and hypoxaemia when compared with standard low-flow oxygen therapy [26]. We also did not attempt a formal meta-analytic pooling of effect estimates, given the heterogeneity just described, so the predictor rankings offered here should be read as a qualitative synthesis of a broadly consistent literature rather than a precise, quantitatively pooled risk model.

5. Conclusion

Bacterial pneumonia remains a leading cause of preventable death in children, but the evidence accumulated since the early 2000s identifies a reasonably consistent, short list of bedside predictors of who among affected children is most likely to die: hypoxaemia, severe acute malnutrition, young age, altered consciousness, and HIV infection or exposure [6,18,13]. Composite severity scores built from these predictors improve on any single sign in isolation but require local recalibration to perform well outside their derivation setting, and their long-term value depends on continued access to effective antibiotics and oxygen therapy, both of which are being eroded in some regions by rising antimicrobial resistance even as pneumococcal conjugate vaccination reduces the overall size of the at-risk population [22,15,25]. Future work would benefit less from identifying additional predictors than from validating existing severity tools in contemporary, post-vaccine cohorts and from tracking how antimicrobial resistance trends interact with the treatment pathways that risk stratification is meant to

trigger.

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8. Conflict of Interest

The authors declare no conflict of interest.

9. Author Contributions

All authors contributed to the conception of the review, the interpretation of the synthesized literature, and the drafting and critical revision of the manuscript, and all authors approved the final version submitted for publication.

10. Ethics Statement

This review synthesizes previously published, publicly available data and did not involve new data collection from human participants; no institutional ethics approval was required.

11. Data Availability

No new data were generated for this review. All sources synthesized are cited in the reference list and are publicly available through their respective publishers.

12. References

1. Rudan, I., Boschi-Pinto, C., Biloglav, Z., Mulholland, K., Campbell, H. (2008) Epidemiology and etiology of childhood pneumonia. *Bulletin of the World Health Organization*, 86(5): 408-416. DOI: [10.2471/BLT.07.048769](https://doi.org/10.2471/BLT.07.048769)
2. Walker, C.L.F., Rudan, I., Liu, L., Nair, H., Theodoratou, E., Bhutta, Z.A., et al. (2013) Global burden of childhood pneumonia and diarrhoea. *Lancet*, 381(9875): 1405-1416.

DOI: [10.1016/S0140-6736\(13\)60222-6](https://doi.org/10.1016/S0140-6736(13)60222-6)

3. Liu, L., Oza, S., Hogan, D., Perin, J., Rudan, I., Lawn, J.E., et al. (2016) Global, regional, and national causes of under-5 mortality in 2000-15: an updated systematic analysis with implications for the Sustainable Development Goals. *Lancet*, 388(10063): 3027-3035. DOI: [10.1016/S0140-6736\(16\)31593-8](https://doi.org/10.1016/S0140-6736(16)31593-8)
4. GBD 2016 Lower Respiratory Infections Collaborators (2018) Estimates of the global, regional, and national morbidity, mortality, and aetiologies of lower respiratory infections in 195 countries, 1990-2016. *Lancet Infectious Diseases*, 18(11): 1191-1210. DOI: [10.1016/S1473-3099\(18\)30310-4](https://doi.org/10.1016/S1473-3099(18)30310-4)
5. McAllister, D.A., Liu, L., Shi, T., Chu, Y., Reed, C., Burrows, J., et al. (2019) Global, regional, and national estimates of pneumonia morbidity and mortality in children younger than 5 years between 2000 and 2015. *Lancet Global Health*, 7(1): e47-e57. DOI: [10.1016/S2214-109X\(18\)30408-X](https://doi.org/10.1016/S2214-109X(18)30408-X)
6. Djelantik, I.G.G., Gessner, B.D., Sutanto, A., Steinhoff, M., Linehan, M., Moulton, L.H., Arjoso, S. (2003) Case fatality proportions and predictive factors for mortality among children hospitalized with severe pneumonia in a rural developing country setting. *Journal of Tropical Pediatrics*, 49(6): 327-332. DOI: [10.1093/tropej/49.6.327](https://doi.org/10.1093/tropej/49.6.327)
7. Scott, J.A.G., Brooks, W.A., Peiris, J.S.M., Holtzman, D., Mulholland, E.K. (2008) Pneumonia research to reduce childhood mortality in the developing world. *Journal of Clinical Investigation*, 118(4): 1291-1300. DOI: [10.1172/JCI33947](https://doi.org/10.1172/JCI33947)
8. Reed, C., Madhi, S.A., Klugman, K.P., Kuwanda, L., Ortiz, J.R., Finelli, L., Fry, A.M. (2012) Development of the Respiratory Index of Severity in Children (RISC) score among young children with respiratory infections in South Africa. *PLoS One*, 7(11): e27793. DOI: [10.1371/journal.pone.0027793](https://doi.org/10.1371/journal.pone.0027793)
9. World Health Organization (2014) Revised WHO classification and treatment of childhood pneumonia at health facilities: evidence summaries. Geneva: World Health Organization.
10. Izadnegahdar, R., Cohen, A.L., Klugman, K.P., Qazi, S.A. (2013) Childhood pneumonia in developing countries. *Lancet Respiratory Medicine*, 1(7): 574-584. DOI: [10.1016/S2213-2600\(13\)70075-4](https://doi.org/10.1016/S2213-2600(13)70075-4)
11. Lazzerini, M., Sonogo, M., Pellegrin, M.C. (2015) Hypoxaemia as a mortality risk factor in acute lower respiratory infections in children in low and middle-income countries: systematic review and meta-analysis. *PLoS One*, 10(9): e0136166. DOI: [10.1371/journal.pone.0136166](https://doi.org/10.1371/journal.pone.0136166)
12. Chisti, M.J., Tebruegge, M., La Vincente, S., Graham, S.M., Duke, T. (2009) Pneumonia in severely malnourished children in developing countries - mortality risk, aetiology and validity of WHO clinical signs: a systematic review. *Tropical Medicine & International Health*, 14(10): 1173-1189. DOI: [10.1111/j.1365-3156.2009.02364.x](https://doi.org/10.1111/j.1365-3156.2009.02364.x)
13. Preidis, G.A., McCollum, E.D., Mwansambo, C., Kazembe, P.N., Schutze, G.E., Kline, M.W. (2011) Pneumonia and malnutrition are highly predictive of mortality among African children hospitalized with human immunodeficiency virus infection or exposure in the era of antiretroviral therapy. *Journal of Pediatrics*, 159(3): 484-489. DOI: [10.1016/j.jpeds.2011.02.033](https://doi.org/10.1016/j.jpeds.2011.02.033)
14. Duke, T. (2005) Neonatal pneumonia in developing countries. *Archives of Disease in Childhood - Fetal and Neonatal Edition*, 90(3): F211-F219. DOI: [10.1136/adc.2003.048108](https://doi.org/10.1136/adc.2003.048108)
15. Alhusseini, L.B., Sadeghi Ghazi Chaki, S., Noshak, M.A., Azizian, K., Kouhsari, E. (2025) Cell wall-inhibiting antibiotics resistance in *Streptococcus pneumoniae* causing invasive diseases: a global systematic review and meta-analysis in pediatric populations. *Italian Journal of Pediatrics*, 51: 322. DOI: [10.1186/s13052-025-02161-x](https://doi.org/10.1186/s13052-025-02161-x)
16. Brandileone, M.C.C., Vieira, V.S.D., Casagrande, S.T., Zanella, R.C., Guerra, M.L.L.S., Bokermann, S., et al. (1997) Prevalence of serotypes and antimicrobial resistance of *Streptococcus pneumoniae* strains isolated from Brazilian children with invasive infections. *Microbial Drug Resistance*, 3(2): 141-146.

DOI: [10.1089/mdr.1997.3.141](https://doi.org/10.1089/mdr.1997.3.141)

17. Jroundi, I., Mahraoui, C., Benmessaoud, R., Moraleda, C., Tornimbene, B., Valles, X., et al. (2014) Risk factors for a poor outcome among children admitted with clinically severe pneumonia to a university hospital in Rabat, Morocco. *International Journal of Infectious Diseases*, 28: 164-170. DOI: [10.1016/j.ijid.2014.07.027](https://doi.org/10.1016/j.ijid.2014.07.027)
18. Sonogo, M., Pellegrin, M.C., Becker, G., Lazzerini, M. (2015) Risk factors for mortality from acute lower respiratory infections (ALRI) in children under five years of age in low and middle-income countries: a systematic review and meta-analysis of observational studies. *PLoS One*, 10(1): e0116380. DOI: [10.1371/journal.pone.0116380](https://doi.org/10.1371/journal.pone.0116380)
19. Chisti, M.J., Duke, T., Robertson, C.F., Ahmed, T., Faruque, A.S.G., Bardhan, P.K., et al. (2012) Clinical predictors and outcome of hypoxaemia among under-five diarrhoeal children with or without pneumonia in an urban hospital, Dhaka, Bangladesh. *Tropical Medicine & International Health*, 17(1): 106-111. DOI: [10.1111/j.1365-3156.2011.02890.x](https://doi.org/10.1111/j.1365-3156.2011.02890.x)
20. Bassat, Q., Lanaspá, M., Machevo, S., O'Callaghan-Gordo, C., Sigauque, B., Nhampossa, T., et al. (2016) Hypoxaemia in Mozambican children under five years of age admitted to hospital with clinical severe pneumonia: clinical features and performance of predictor models. *Tropical Medicine & International Health*, 21(9): 1147-1156. DOI: [10.1111/tmi.12738](https://doi.org/10.1111/tmi.12738)
21. Ayieko, P., English, M. (2006) In children aged 2-59 months with pneumonia, which clinical signs best predict hypoxaemia? *Journal of Tropical Pediatrics*, 52(5): 307-310. DOI: [10.1093/tropej/fml036](https://doi.org/10.1093/tropej/fml036)
22. Hooli, S., Colbourn, T., Lufesi, N., Costello, A., Nambiar, B., Thammasitboon, S., et al. (2016) Predicting hospitalised paediatric pneumonia mortality risk: an external validation of RISC and mRISC, and local tool development (RISC-Malawi) from Malawi. *PLoS One*, 11(12): e0168126. DOI: [10.1371/journal.pone.0168126](https://doi.org/10.1371/journal.pone.0168126)
23. Wilkes, C., Bava, M., Graham, H.R., Duke, T. (2023) What are the risk factors for death among children with pneumonia in low- and middle-income countries? A systematic review. *Journal of Global Health*, 13: 05003. DOI: [10.7189/jogh.13.05003](https://doi.org/10.7189/jogh.13.05003)
24. Enarson, P.M., Gie, R.P., Enarson, D.A., Mulholland, E.K. (2014) Reducing deaths from severe pneumonia in children in Malawi by improving delivery of pneumonia case management. *PLoS One*, 9(7): e102955. DOI: [10.1371/journal.pone.0102955](https://doi.org/10.1371/journal.pone.0102955)
25. Kleynhans, J., Tempia, S., Shioda, K., von Gottberg, A., Weinberger, D.M., Cohen, C. (2021) Estimated impact of the pneumococcal conjugate vaccine on pneumonia mortality in South Africa, 1999 through 2016: an ecological modelling study. *PLoS Medicine*, 18(2): e1003537. DOI: [10.1371/journal.pmed.1003537](https://doi.org/10.1371/journal.pmed.1003537)
26. Chisti, M.J., Salam, M.A., Smith, J.H., Ahmed, T., Pietroni, M.A.C., Shahunja, K.M., et al. (2015) Bubble continuous positive airway pressure for children with severe pneumonia and hypoxaemia in Bangladesh: an open, randomised controlled trial. *Lancet*, 386(9998): 1057-1065. DOI: [10.1016/S0140-6736\(15\)60249-5](https://doi.org/10.1016/S0140-6736(15)60249-5)