Title

Tuberculosis prevalence among children with severe acute malnutrition: a systematic review and meta-analysis

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ABSTRACT
Introduction
Control of tuberculosis (TB) in children remains a major challenge globally. There is growing recognition that children with severe acute malnutrition (SAM) are a high-risk

population for TB, but the global burden of TB in this group has never been comprehensively quantified.

Methods
We conducted a systematic review and meta-analysis to estimate the prevalence of TB among children with SAM. Following PRISMA guidelines, we searched PubMed/MEDLINE, Embase, Scopus, Web of Science, Cochrane Library, and WHO Global Index Medicus from database inception to June 15, 2026. We included studies reporting TB among systematically sampled cohorts of children <15 years with SAM as defined by the World Health Organization. Methodological study quality was assessed with adapted versions of the Newcastle-Ottawa Scale or the Joanna Briggs Institute critical appraisal checklist. Pooled TB prevalence was calculated using a random-effects model with predefined stratification of studies by geographic region, national TB incidence, and study quality. We also conducted subgroup analyses by age, sex, HIV status, SAM type, and TB exposure.

Results
We included 73 studies comprising 33,869 children with SAM across 15 countries, predominantly from sub-Saharan Africa and South Asia, and predominantly reporting on hospitalized children. The pooled TB prevalence was 13% (95% CI: 11-16%), but there was substantial heterogeneity (I^2=98%). Studies conducted in Southern Africa had the highest pooled TB prevalence (36%, 95% CI: 19-56%) compared to other regions ($p<0.01$). Pooled TB prevalence was higher in those with history of TB household exposure compared to those without (74% vs. 17%, $p=0.01$).

Conclusions
Approximately one in eight children hospitalized with SAM have TB, greatest among children with history of TB exposure and those in Southern Africa. These findings highlight opportunities for improved early TB diagnosis and routine, integrated TB screening within hospital-based SAM care pathways.

Keywords: severe acute malnutrition, tuberculosis, meta-analysis, prevalence, pediatrics

BACKGROUND

Children carry a substantial burden of tuberculosis (TB), with an estimated 1.1 million children <15 years old suffering from the disease resulting in 170,000 deaths from TB in 2024. Using World Health Organization (WHO) estimates, Southeast Asia and Africa WHO Regions have the highest prevalence of TB in the <15 years age group: about 7.3 per 100,000 (or 0.073%) [1]. Poor nutritional status can progress to

secondary immunodeficiency that increases an individual's risk of progressing to TB disease if they are infected with *M. tuberculosis*, and having severe forms of the disease and higher mortality [2–4]. There is growing recognition of the interplay between malnutrition and TB in children, and the WHO now highlights children with severe acute malnutrition (SAM) as a key high-risk group for targeted efforts for improved TB diagnosis [5,6]. SAM encompasses both severe wasting (formerly known as marasmus) and edematous malnutrition (formerly known as kwashiorkor). The WHO defines severe wasting as: weight-for-length/height z-score <-3 or mid-upper arm circumference (MUAC) <11.5 cm for those 6 to 59 months old, and Body Mass Index (BMI)-for-age z-score <-3 or MUAC-for-age z-score <-3. Edematous malnutrition is SAM characterized by the presence of bilateral pitting edema [7]. Although the global epidemiology of edematous malnutrition is not well described, in 2024 there were an estimated 12.2 million children under 5 years old with severe wasting globally, with most of these children in Asia (76%) and Africa (22%) [8].

Two recent systematic reviews have evaluated the risk for TB in the context of malnutrition. One review evaluated undernutrition (BMI <18.5 kg/m^2 for adults) as a binary risk factor for incident TB disease. Data from all age groups were included, but most included studies only reporting on adults. Meta-analysis showed that undernutrition was associated with a relative risk of 1.96 (95% CI 1.73-2.21) for incident TB.[9] The other review evaluated the relationship between BMI as a continuous variable and TB risk exclusively in adults, using a more refined analytical approach with assessment of log-linear relationships. Meta-analysis revealed an inverse dose-response whereby decreasing BMI was associated with increasing incident TB risk, with a relative risk of 5.8 (95% CI 4.8-7.0) for BMI 16.0 kg/m^2 versus 25 kg/m^2 [10].

Despite the explicit biological and clinical connection between TB and SAM, the burden of TB in children with SAM is not well characterized across different settings. Inconsistent definitions for SAM and pediatric TB diagnostic criteria, underreporting, and limited integration of TB screening into malnutrition protocols have hindered accurate estimation of the co-prevalence of these conditions [11]. Alone, TB and SAM are key drivers of preventable mortality in young children globally. When these conditions co-occur, mortality risk compounds, as demonstrated by two large studies showing that children with SAM have two to three times greater risk of mortality when they have co-morbid TB compared to those without TB [12,13]. Given the high individual and combined morbidity and mortality of TB and SAM, improved understanding of their intersection is urgently needed to inform targeted screening, diagnosis, and treatment interventions [3]. We therefore conducted a systematic review and meta-analysis to estimate the prevalence of TB among children with WHO-defined SAM receiving clinical care, with particular relevance to TB-endemic countries.

METHODS

Study Registration

This systematic review and meta-analysis was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist [14]. The completed checklist is Table S1 in the Online Supplementary Document. The review protocol and records are available online through the Prospective Register of Systematic Reviews (PROSPERO: CRD420251057369).

Eligibility Criteria

We included observational studies (cross-sectional and cohort) and surveillance reports that reported the prevalence of TB among children <15 years old diagnosed with SAM. Interventional studies were also included if they reported baseline prevalence of TB prior to intervention. Studies reporting on a mixed population with some not having SAM could be included if separate results were reported for only those with SAM. SAM had to be defined according to WHO criteria (see above) [7]. Children with SAM could be receiving either inpatient or outpatient care. Enumeration of children with TB could entail either robust research-based definitions or programmatic/routine diagnoses. Studies were excluded if they did not report extractable data on TB prevalence among children with WHO-defined SAM, did not report data specifically for individuals <15 years old, or utilized study designs that did not systematically sample children with SAM.

Data Sources and Search Strategy

A comprehensive search of the electronic databases including PubMed/MEDLINE, EMBASE, Scopus, Web of Science, Cochrane Library, and WHO Global Index Medicus was performed from database inception to June 15, 2026. Search strategy included the following terms and combinations: ('severe acute malnutrition' OR kwashiorkor OR 'protein-energy malnutrition' OR 'nutritional edema' OR 'nutritional oedema' OR marasmus OR 'severe wasting') AND tuberculosis. Searches using medical subject heading (MeSH) terms were conducted in PubMed, including the terms 'severe acute malnutrition' AND 'tuberculosis.' Details of the search strategy can be found in Appendix S1 in the Online Supplementary Document. To identify any relevant published or unpublished data not identified with our electronic search, 1) the reference lists of all included studies and relevant review articles were screened for potentially eligible studies, 2) we contacted experts in the field of child TB and SAM, and 3) datasets from grey literature (e.g., conference abstracts, government reports) were reviewed and considered for inclusion. No language or date restrictions were applied.

Study Selection & Data Extraction

Two independent reviewers (AAK, JAM, AV, or BJV) screened titles and abstracts, followed by full-text review using predefined inclusion criteria. We used Covidence Systematic Review Software (Veritas Health Innovation, Melbourne, www.covidence.org) to manage the selection of studies. Data were extracted independently by two reviewers (AAK, JAM, or BJV) using a standardized form and entered into an Excel database capturing: title, first author, publication year, design type, country, summarized patient age, proportion female, number of children with SAM, number with edematous vs. non-edematous SAM, number of children with TB (including breakdown of microbiologically confirmed and clinical diagnoses without confirmation, as feasible), TB diagnostic criteria utilized, HIV prevalence, BCG immunization coverage, and history of TB exposure prevalence. Discordance between the first two reviewers on screening of titles and abstracts, review of full texts, and data on the number of children with SAM or TB was resolved by discussion amongst the reviewers or evaluation by the third reviewer.

Assessment of Study Quality

Methodological study quality was assessed independently by two reviewers (AAK, JAM, or BJV) using the Newcastle-Ottawa Scale [15] for cohort studies and the Joanna Briggs Institute critical appraisal checklist [16] for cross-sectional studies, both tailored to this review and available in Appendix S2 the Online Supplementary Document. Prespecified score ranges for both tools were used to classify each study as 'low,' 'moderate,' or 'high' quality. Discrepancies in classification between the first two reviewers were resolved by discussion amongst the reviewers or evaluation by the third reviewer.

Statistical Analysis

To estimate the pooled prevalence of TB in the included studies, we used a random effects meta-analysis with the metaprop command in Stata version 19 (StataCorp, College Station, USA). We conducted prespecified stratified meta-analyses with stratification of studies by United Nations geoscheme subregion, national TB annual incidence [1], and study quality. We planned prespecified meta-analyses of the following subgroups: HIV status, history of TB exposure, categorized age, sex, SAM type (edematous vs non-edematous), setting (e.g. inpatient vs outpatient), diagnostic method (microbiologic/confirmed vs clinical/unconfirmed), and BCG vaccination. However, subgroup meta-analyses were only conducted if at least five included studies reported data for a particular subgroup, and therefore subgroup analyses by setting, diagnostic method, and BCG vaccination were not conducted. One study was identified as a statistical and methodologic outlier, and therefore a post-hoc leave-one-out sensitivity analyses was performed with this study excluded and meta-analyses repeated.

Prevalence estimates for each study and each pooled estimate were reported with 95% confidence intervals (CIs), with forest plots generated. Heterogeneity was assessed using the I^2 statistic. Variation was considered to be high when I^2 was 75% or larger [17]. Statistically significant differences were defined by $p<0.05$. Because heterogeneity was very high, we did not evaluate for publication bias [18].

RESULTS

Study Selection

Figure 1 depicts the study selection process. A total of 504 records were identified through database searches. Title and abstract screening included 380 records, 167 full-text articles were assessed for eligibility, and 69 were retained after full-text review. An additional four studies were identified outside the search so that 73 studies were included in total.

Study Characteristics

The 73 included studies reported on a total of 33,869 children with SAM, with study sizes ranging from 45 to 9540 participants. All studies were conducted in sub-Saharan Africa or South Asia. One study was reported in French (Clavier-Rogez 2015), and all other studies were reported in English. All the studies were observational in design, including 32 cohort studies and 41 cross-sectional studies. Studies were

conducted between 2003 and 2025, with most studies conducted in the past decade. All studies were conducted primarily in inpatient hospital-based settings, though one cohort study reported on an extensive follow-up period mostly in the outpatient setting after TB diagnosis was made during hospitalization (Clavier-Rogez 2015) and the TB ALGO PED study recruited 3% of the cohort from outpatient facilities and 97% from inpatient facilities. Most participants were less than five years old, with reported median or mean ages ranging from 10 to 36 months. Among studies reporting sex distribution, the proportion of female participants ranged from 16% to 66%, with most studies demonstrating a relatively balanced distribution. Studies reported HIV prevalences ranging from 0% to 51%. For study quality assessments, 17 (23%) studies were classified as high quality, 28 (38%) as moderate quality, and 28 (38%) as low quality. There were 8 (11%) studies conducted in TB high-incidence countries (national annual incidence >250 per 100,000), 34 (47%) studies in medium-incidence countries (150 to 250 per 100,000), and 31 (42%) studies in low-incidence countries (<150 per 100,000). Study characteristics are summarized in Table 1.

Table 1: Characteristics of the included studies.

Study	Country(s) where conducted	Year(s) study conducted	Study design	Number with SAM	Study population age (months)	% Female	% living with HIV	Study quality
Abdi 2025[19]	Ethiopia	2020-2021	Retrospective Cohort	366	Mean 12 (SD NR)	46	NR	Low
Adem 2020[20]	Ethiopia	2018	Prospective Cohort	133	60% between 6-23	51	2	Moderate
Ahmad 2008[21]	Malawi	2003-2004	Prospective Cohort	89	Median 22 (IQR 16-32)	46	43	Moderate
Ahmed 2021[22]	India	2020-2021	Cross-sectional (Direction NR)	150	NR	NR	NR	Low
Ahmed 2023[23]	Ethiopia	2021	Retrospective Cohort	712	Median 18 (IQR 12-23)	45	0.4	Low
Anshuman 2023[24]	India	2022-2023	Cross-sectional (Direction NR)	144	NR	NR	NR	Moderate
Asafo-Agyei 2013[25]	Ghana	2010	Prospective Cross-sectional	246	Median 15 (IQR 10-24)	55	27	High
Ashine 2020[26]	Ethiopia	2017-2019	Retrospective Cohort	346	Mean 18 (SD 5)	39	11	Low
Asiimwe 2025[27]	Uganda	2023-2024	Prospective Cross-sectional	137	46% 12-23	41	3	High
Atalell 2022[28]	Ethiopia	2018-2020	Retrospective Cross-sectional	414	NR	44	5	High
Aye 2023[29]	Ethiopia	2020	Retrospective Cross-sectional	162	Mean 21 (SD 11)	46	7	Moderate
Aynalem 2023[30]	Ethiopia	2017-2019	Retrospective Cohort	345	63% <24	39	7	High
Banga 2020[31]	Uganda	2019	Prospective Cohort	338	85% <24	39	6	Moderate
Baraki 2020[32]	Ethiopia	2012-2016	Retrospective Cohort	1690	68% <24	54	3	Low
Bello 2025[33]	Nigeria	NR	Prospective Cross-sectional	146	Mean 17 (SD 7)	44	1	Moderate
Bhat 2013[34]	India	2012	Retrospective Cross-sectional	430	39% between 12-35	66	NR	High
Bitew 2020[35]	Ethiopia	2012-2019	Retrospective Cohort	515	74% <24	50	NR	Low

Bizuneh 2022[36]	Ethiopia	2015-2019	Retrospective Cross-sectional	454	Median 26 (SD 17)	55	8	Moderate
Chabala 2024[37]	Zambia, Uganda	2019-2022	Prospective Cohort	603	Median 15 (IQR 11-20)	43	11	High
Chama 2024[38]	Zambia	2020-2022	Retrospective Cross-sectional	116	Median 16 (IQR NR)	47	20	High
Clavier-Rogez 2015[39]	Chad	2010-2011	Cohort (Direction NR)	168	Mean 18 (SD 8)	39	NR	Moderate
De Maayer 2011[40]	South Africa	Not reported	Prospective Cohort	113	Median 10 (IQR 1-34)	49	51	Moderate
Desyibelew 2017[41]	Ethiopia	2012-2016	Retrospective Cross-sectional	401	Mean 24 (SD 15)	44	6	Moderate
Fedlu 2025[42]	Ethiopia	2020-2021	Retrospective Cohort	323	Mean 25 (SD 18)	50	NR	Low
Fikrie 2019[43]	Ethiopia	2015-2017	Retrospective Cohort	381	Mean 23 (SD 16)	50	1	Low
Gaurav 2023[44]	India	2021-2023	Prospective Cross-sectional	208	59% <24	56	0.5	Moderate
Girma 2013[45]	Ethiopia	2009-2011	Prospective Cohort	351	Median 36 (IQR 24-60)	43	3	High
Girum 2017[46]	Ethiopia	2013-2015	Retrospective Cohort	545	Median 24 (IQR 12-36)	47	NR	Low
Gupta 2015[47]	India	2012-2014	Retrospective Cross-sectional	421	Mean 16 (SD NR)	57	NR	Moderate
Haider 2021[48]	India	NR	Cross-sectional (Direction NR)	50	NR	NR	2	Low
Hossain 2009[49]	Bangladesh	2005-2006	Cohort (Direction NR)	171	Mean 23 (SD 15)	NR	NR	Low
Hundiwala 2026[50]	India	2022-2023	Prospective Cohort	280	Mean 18 (SD 10)	41	NR	Low
Ide 2019[51]	Sierra Leone	2018	Prospective Cross-sectional	74	Median 11 (IQR 10)	46	NR	High
Ikobah 2022[52]	Nigeria	2017-2019	Prospective Cohort	100	Mean 14 (SD 14)	54	12	Low
Kabeta 2017[53]	Ethiopia	2013-2015	Retrospective Cohort	191	Median 12 (IQR 9)	NR	NR	Low
Kabthymer 2020[54]	Ethiopia	2015-2017	Retrospective Cohort	375	Mean 27 (SD 15)	51	4	Low
Kachhwaha 2023[55]	India	2018-2019	Prospective Cross-sectional	429	11.2% < 24	50	NR	High
Kassaw 2021[56]	Ethiopia	2016-2019	Retrospective Cross-sectional	476	Median 14 (IQR NR)	48	7	Low
Khalil 2020[57]	Pakistan	2018	Prospective Cross-sectional	190	24% between 1-12	NR	NR	Moderate
Kumar 2012[58]	India	2010-2011	Prospective Cross-sectional	76	Mean 36 (SD 16)	45	4	Moderate
Kumar 2014[59]	India	2011-2012	Cross-sectional (Direction NR)	104	Mean 14 (SD NR)	52	3	Moderate
Kumar 2023[60]	India	NR	Cross-sectional (Direction NR)	200	NR	NR	3	Low
Kumar 2025[61]	India	NR	Cross-sectional (Direction NR)	90	41% between 12-36	34	1	Low
Kyasa 2024[62]	India	NR	Prospective Cross-sectional	110	44% between 6-23	54	NR	Low
LaCourse 2014[63]	Malawi	2012	Prospective Cohort	300	Median 19 (IQR 12-25)	51	17	High
Majid 2023[64]	India	2019-2022	Cross-sectional (Direction NR)	306	NR	58	NR	Low
Mekonnen 2025[65]	Ethiopia	2017-2021	Retrospective Cohort	395	59% between 6-23	48	3	Low

Mezemir 2022[66]	Ethiopia	2016-2019	Retrospective Cross-sectional	385	Mean 18 (SD 10)	46	0	Moderate
Munthali 2017[12]	Zambia	2009-2013	Retrospective Cross-sectional	9540	Median 17 (IQR 22-55)	46	32	Moderate
Nambuya 2025[67]	Uganda	2014-2015	Prospective Cross-sectional	400	48% between 13-24	42	11	Moderate
Nasir 2023[68]	Ethiopia	2007-2021	Retrospective Cross-sectional	261	Median 3 (IQR 2-5)	59	NR	Moderate
Nath 2020[69]	India	2018-2019	Prospective Cross-sectional	50	Mean 2 (SD 15)	16	NR	Moderate
Nienaber 2024[70]	Botswana, Ghana, and South Africa	2013-2018	Retrospective Cross-sectional	843	NR	NR	13	Low
Osorio 2020[71]	Mozambique	2018	Retrospective Cross-sectional	45	Mean 17 (SD 5)	NR	22	High
Oumer 2021[72]	Ethiopia	2017-2020	Retrospective Cohort	665	Mean 20 (SD 15)	45	1	Low
Page 2013[73]	Niger	2007 to 2008	Prospective Cohort	311	Median 13 (IQR 10-24)	45	1	Moderate
Panda 2023[74]	India	NR	Prospective Cohort	60	Mean 12 (SD 12)	35	NR	Moderate
Pathak 2021[75]	India	NR	Cross-sectional (Direction NR)	300	NR	NR	2	Low
Pathak 2026[76]	India	2023-2024	Prospective Cross-sectional	65	78% between 12-60	37	NR	Moderate
Prabhakar 2025[77]	India	2025	Retrospective Cross-sectional	70	46% between 12-24	60	NR	Moderate
Radhan 2021[78]	Pakistan	2019-2020	Cross-sectional (Direction NR)	50	Mean 21 (SD 15)	32	NR	Moderate
Sahay 2024[79]	India	NR	Cross-sectional (Direction NR)	200	NR	NR	3	Low
Sathenahalli 2015[80]	India	2011-2012	Prospective Cohort	104	60% between 6-12	52	3	High
Singh 2021[81]	India	2017	Retrospective Cross-sectional	3230	NR	52	NR	High
Solanki 2025[82]	India	2015-2016	Prospective Cross-sectional	93	Mean 25 (SD 15)	57	NR	Moderate
TB ALGO PED (unpublished)	Niger, Nigeria	2023-2025	Prospective Cohort	1152	Median 16 (IQR 10-24)	45	2	High
Thakur 2022[83]	Nepal	2018-2019	Prospective Cohort	107	Median 22 (IQR 13-37)	39	NR	High
Thapa 2015[84]	Nepal	2013-2014	Prospective Cross-sectional	77	Mean 23 (SD NR)	51	NR	Moderate
Thomas 2022[85]	South Africa	2015-2017	Retrospective Cohort	95	Median 12 (IQR 8-17)	NR	9	Low
Vonasek 2026[86]	Malawi	2021-2022; 2023-2024	Prospective Cross-sectional	341	Mean 20 (SD 12)	51	9	High
Wagnew 2019[87]	Ethiopia	2014-2016	Retrospective Cross-sectional	416	Median 18 (IQR NR)	50	5	Low
Wake 2024[88]	Ethiopia	2018-2022	Retrospective Cohort	247	Median 12 (IQR NR)	47	0	Moderate
Wondim 2020[89]	Ethiopia	2013-2017	Retrospective Cohort	398	Median 19 (IQR 12-32)	44	0.03	Low

IQR: interquartile Range, NR: not reported, SAM: severe acute malnutrition, SD: standard deviation

Meta-analyses

The pooled prevalence of TB among children with SAM from all included studies was 13% (95% CI 11-16%) but with high heterogeneity (I^2 = 98%, p<0.01) and study-specific prevalences ranging from 1% (95% CI 1-3%) to 73% (95% CI 68-78%), as shown in Figure 2.

Meta-analyses with studies stratified by United Nations geoscheme subregion, study quality, and national TB annual incidence are summarized in Table 2 and detailed in forest plots in Figures S1, S2, and S3 in the Online Supplementary Document, respectively. The pooled TB prevalence was significantly higher (p<0.001) for studies conducted in Southern Africa (36%, 95% CI 19-56%) compared to other subregions. There was no significant variation in pooled TB prevalence after stratifying by study quality (p=0.331) or national TB annual incidence (p=0.285). Heterogeneity was high across all strata with I^2 of 93% or higher (all with p<0.01).

Meta-analyses for subgroups defined by participant HIV status, history of TB exposure, age, sex, and SAM type are summarized in Table 2 and detailed in forest plots in Figures S4, S5, S6, S7, and S8 in the Online Supplementary Document, respectively. There was a trend towards higher pooled TB prevalence for those living with HIV, but the difference was not statistically significant (43% vs 12%, p=0.08). Pooled TB prevalence was higher for those with history of TB exposure (74% vs 17%, p=0.009). Heterogeneity was high across all subgroups with I^2 of 80% or higher (all with p<0.01).

One study (LaCourse 2014) was identified as a statistical and methodologic outlier (detailed in the Discussion below). Repeated meta-analyses with this study excluded are shown in Table S2 in the Online Supplementary Document. The overall pooled prevalence was still 13% with a slightly narrower 95% CI (11-15%), and there were no notable changes to results from the meta-analyses with stratification of studies or subgroups.

Table 2. Pooled prevalence of TB among children with SAM by stratified and subgroup meta-analyses.

	N	**Prevalence (95% CI)**	**I^2**	***p*-value**
All studies	73	13% (11-16%)	98%	-
<u>UN geoscheme subregion</u>				
Eastern Africa	28	11% (9-13%)	93%	<0.001
Southern Africa	7	36% (19-56%)	98%	
Southern Asia	29	11% (8-15%)	97%	
Western Africa	7	15% (6-27%)	97%	
<u>Study quality</u>				
Low	28	12% (9-15%)	94%	0.331
Moderate	28	13% (8-18%)	98%	
High	17	17% (11-24%)	98%	
<u>Nation annual TB incidence</u>				
Low (<150 per 100,000)	31	13% (10-17%)	97%	0.285
Medium (150-250 per 100,000)	34	11% (9-14%)	93%	
High (>250 per 100,000)	8	26% (8-48%)	99%	
<u>HIV status</u>				
Infected	7	43% (11-78%)	99%	0.080

Negative	6	12% (3-26%)	99%	
History of TB exposure				
None	6	17% (5-35%)	99%	0.009
Present	6	74% (33-99%)	97%	
Age				
<24 months	8	11% (7-15%)	83%	0.297
≥24 months	8	15% (8-22%)	81%	
Sex				
Female	12	20% (8-36%)	99%	0.797
Male	12	18% (7-32%)	99%	
SAM type				
No nutritional edema	7	24% (13-38%)	97%	0.986
Nutritional edema present	7	24% (10-42%)	96%	

CI: confidence interval, N: number of studies in the meta-analysis, SAM: severe acute malnutrition, TB: tuberculosis, UN: United Nations

DISCUSSION

In this systematic review of TB prevalence in children with WHO-defined SAM the pooled prevalence was strikingly high at 13% (95% CI: 11–16%). This review included data from over thirty thousand children, almost all of whom were hospitalized with SAM. All included studies were conducted in sub-Saharan Africa or South Asia, which reflects the regions where most children with SAM reside [8] and where over half of the global burden of TB is estimated to occur [1]. TB prevalence was highly heterogeneous across studies. Subgroup analyses did not demonstrate key drivers of the heterogeneity, but were notable for significantly higher TB prevalence in those with a history of TB exposure and a trend towards higher prevalence in those living with HIV, though that trend was not statistically significant. To our knowledge, this is the first systematic review of TB prevalence in children with SAM.

Malnutrition and TB share a bidirectional biological relationship, resulting in the high prevalence of TB in children with SAM that we report in this review. Malnutrition impairs both innate and adaptive immunity, increasing susceptibility to TB [2,90]. In the other direction of this relationship, TB also exacerbates malnutrition [90]. Compounding the biologic connections between malnutrition and TB are social and economic factors that promote both conditions. TB and SAM tend to occur most frequently in marginalized populations of children living in poverty with poor access to health care services.

Our findings may underestimate the true burden of TB in children hospitalized with SAM. Most of the data in this review are from children less than five years old, the age group most affected by SAM. According to the WHO, an estimated 58% of children in this age group with TB globally were not diagnosed or reported to have TB in 2022 [5]. Particularly for the included retrospective studies (N=32), reliance on routine diagnosis of TB may have led to underestimation of TB prevalence. A major component of our study quality assessments in this review was the robustness of the TB diagnostic criteria, and 38% of included studies were ‘low’ quality largely because of limited description of the TB in the manuscript or reliance on routine diagnosis and reporting of TB. With more intensive diagnostic workup under research conditions and using more

rigorous TB diagnostic criteria, fewer missed diagnoses and higher estimation of TB prevalence in young children could be expected. However, when we stratified pooled TB prevalence estimates by the three study quality categories, no differences were observed.

The wide range of individual study estimates of TB prevalence (1–73%), which translated into high heterogeneity (I^2 = 98%), was expected given the diversity of settings studied, differences in study design, and different TB diagnostic approaches. TB epidemiology varies widely between and within countries [1]. Surprisingly, when we stratified pooled TB prevalence estimates by categories of national TB incidence for the countries in which individual studies were conducted, no significant differences were observed. On the other hand, we did find differences in pooled TB prevalence when stratifying studies by the region in which they were conducted, with the highest pooled prevalence (36%) for studies conducted in Southern Africa. The study by LaCourse and colleagues had a prevalence estimate of 73% [63], which was 21% more than the point prevalence of the next highest study. This study was the only included study to utilize the first version of the NIH clinical diagnosis definition for child TB [91], while several included studies utilized the revised case definitions published in 2015 [92]. A key change to the case definitions was a shift from five categories (“confirmed,” “probable,” “possible,” “unlikely,” and “not” TB) to three (“confirmed,” “unconfirmed,” and “unlikely”). In the study by LaCourse and colleagues, 66% of participants were classified as “possible” TB [63]. In the binary classification of TB status used in this review, we classified those with “possible” TB as children with TB. Had we only defined children with TB as those classified as “confirmed” and “probable” TB, the TB prevalence from that study would have been much lower at 7%. This scenario exemplifies both the challenge of defining children with TB, even with well-designed clinical studies, and the impact differences in study designs and diagnostic definitions had on the heterogeneous prevalence estimates we report here. Sensitivity analyses with this study excluded did not result in notable changes to the overall pooled TB prevalence estimate or the meta-analyses with stratification of studies or subgroups.

Active screening strategies for TB in children have traditionally focused on two high-risk groups in low- and middle-income countries: close contacts of individuals diagnosed with pulmonary TB and children living with HIV. This review highlights another important TB high-risk group, children hospitalized with SAM, which aligns with the WHO’s new emphasis in recent guidelines for implementing targeted efforts for improved TB diagnosis alongside malnutrition care [5,6]. Children with SAM and HIV—doubling up on risk factors—had an especially high pooled TB prevalence of 43%. In the sub-group analysis, this prevalence was not significantly higher compared to HIV-negative children, and the lack of difference was driven by a large single study that reported very low TB prevalence in both children living with HIV and HIV-negative children (2% and 1%, respectively) [12]. Especially in sub-Saharan Africa, pediatric HIV infection remains unacceptably high, and our data highlight the deadly synergy between HIV, SAM, and TB.

Children with SAM and history of TB exposure—also doubling up on risk factors—had a strikingly high TB prevalence of 74% in subgroup analysis pooling data from six studies. We note the impact of incorporation bias with this association, as history of TB exposure influences the clinical diagnosis of TB in children. Nonetheless,

clinicians caring for children with SAM should always inquire about TB exposure, and when this history is present, there should be a low threshold for initiating treatment for TB disease. Using the recently developed WHO-recommended treatment decision algorithms for child TB, there is a clear recommendation to treat for TB disease when a child with SAM has a history of TB exposure [6], and our data support this approach. The care pathways for management of SAM are longitudinal and offer serial opportunities to assess for TB or establish alternative diagnoses. This programmatic advantage can be leveraged for improved screening and diagnosis of TB, especially if there is strong coordination between TB and malnutrition programs (which otherwise tend to be siloed) to provide integrated services that can benefit children with co-prevalent TB and SAM the most.

The notable strengths of this systematic review and meta-analysis are the large numbers of studies and children included and the restriction to only include studies reporting on children with WHO-defined SAM, which allowed for a consistently defined population that is programmatically relevant. There are noteworthy limitations with this study. First, as detailed above, the TB diagnostic criteria varied amongst the included studies, and the high proportion of 'low' quality included studies was driven by weaker diagnostic criteria. Second, 66% of the studies were from only two countries, Ethiopia and India. Settings with high burden of SAM and TB globally may not be well represented. Third, data on outpatients with SAM were essentially absent. Over the past few decades, guidelines and programs have shifted so that children with SAM receive outpatient, community-based care when they lack medical complications or danger signs [7], and therefore most children with SAM nowadays are initially managed as outpatients. We therefore highlight a need for primary research on the burden of TB in children receiving SAM care as outpatients.

CONCLUSIONS

In summary, our results demonstrate the high burden of TB in children hospitalized with SAM. These results emphasize the urgent need for improved strategies to diagnose TB tailored to this unique population. Building upon the treatment decision algorithms for child TB newly recommended by the WHO in 2022 [6], SAM-specific algorithms could optimize accuracy [37]. Quantifying the high prevalence of TB in children hospitalized with SAM informs policymakers and public health officials about a key population to target for TB case finding efforts and emphasizes to clinicians the importance of having a high index of suspicion for TB when caring for children with SAM.

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Availability of Study Materials: All study materials (template data collection forms, data extracted from included studies, data used for analyses, analytic code, and any other materials) are available from the corresponding author upon request.

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References

1 World Health Organization. Global tuberculosis report. 2025. Available: https://www.who.int/publications/i/item/9789240116924/

2 Jaganath D, Mupere E. Childhood tuberculosis and malnutrition. Journal of Infectious Diseases. 2012;206:1809–15. Medline:23033147 doi:10.1093/infdis/jis608

3 Vonasek BJ, Radtke KK, Vaz P, Buck WC, Chabala C, McCollum ED, et al. Tuberculosis in children with severe acute malnutrition. Expert Rev Respir Med. 2022;16:273–84. Medline:35175880 doi:10.1080/17476348.2022.2043747

4 Basu Roy R, Whittaker E, Seddon JA, Kampmann B. Tuberculosis susceptibility and protection in children. Lancet Infect Dis. 2019;19:e96–108. Medline:30322790 doi:10.1016/S1473-3099(18)30157-9

5 World Health Organization. Roadmap towards ending TB in children and adolescents. 2023. Available: https://www.who.int/publications/i/item/9789240084254

6 World Health Organization. WHO operational handbook on tuberculosis. Module 5: management of tuberculosis in children and adolescents. 2022. Available: https://apps.who.int/iris/bitstream/handle/10665/340256/9789240022614-eng.pdf

7 World Health Organization. Guideline: updates on the Management of Severe Acute Malnutrition in Infants and Children. Geneva; 2013. Available: https://apps.who.int/iris/bitstream/handle/10665/95584/9789241506328_eng.pdf?ua=1

8 World Health Organization, United Nations Children's Fund (UNICEF), World Bank Group. Levels and trends in child malnutrition: UNICEF/WHO/World Bank Group joint child malnutrition estimates: key findings of the 2025 edition. 2025 Jul. Available: https://www.who.int/publications/i/item/9789240112308

9 Franco JVA, Bongaerts B, Metzendorf MI, Risso A, Guo Y, Peña Silva L, et al. Undernutrition as a risk factor for tuberculosis disease. Cochrane Database of Systematic Reviews. 2024;2024. Medline:38860538 doi:10.1002/14651858.CD015890.pub2

10 Saunders MJ, Cegielski JP, Clark RA, Houben RMGJ, McQuaid CF. Body mass index and tuberculosis risk: An updated systematic literature review and dose-

response meta-analysis. Int J Epidemiol. 2025;54. Medline:40922029 doi:10.1093/ije/dyaf154

11 Vonasek BJ, Marcy O, Armour-Marshall J, Casenghi M, Cazes C, Chisti MJ, et al. Leveraging nutritional rehabilitation and tuberculosis programmes to tackle tuberculosis and severe acute malnutrition in children. Lancet Child Adolesc Health. 2025;9:292–4. Medline:40139209 doi:10.1016/S2352-4642(25)00062-8

12 Munthali T, Chabala C, Chama E, Mugode R, Kapata N, Musonda P, et al. Tuberculosis caseload in children with severe acute malnutrition related with high hospital based mortality in Lusaka, Zambia. BMC Res Notes. 2017;10:1–6. Medline:28606173 doi:10.1186/s13104-017-2529-5

13 Wagnew F, Worku W, Dejenu G, Alebel A, Eshetie S. An overview of the case fatality of inpatient severe acute malnutrition in Ethiopia and its association with human immunodeficiency virus/tuberculosis comorbidity-a systematic review and meta-analysis. Int Health. 2018;10:405–11. Medline:29986102 doi:10.1093/inthealth/ihy043

14 Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. Medline:33782057 doi:10.1136/bmj.n71

15 Wells G, O'Connell D, Peterson J, Welch V, Losos M, Tugwell P. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Available: https://ohri.ca/en/who-we-are/core-facilities-and-platforms/ottawa-methods-centre/newcastle-ottawa-scale

16 Barker TH, Hasanoff S, Aromataris E, Stone JC, Leonardi-Bee J, Sears K, et al. The revised JBI critical appraisal tool for the assessment of risk of bias for analytical cross-sectional studies. JBI Evid Synth. 2026;24:401–8. Medline:40521701 doi:10.11124/JBIES-24-00523

17 Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ. 2003;327:557–60. Medline:12958120 doi:10.1136/bmj.327.7414.557

18 Terrin N, Schmid CH, Lau J, Olkin I. Adjusting for publication bias in the presence of heterogeneity. Stat Med. 2003;22:2113–26. Medline:12820277 doi:10.1002/sim.1461

19 Abdi MM, Jama IM, Muse AI, Wedajo GT, Osman MO, Abate KH. Treatment outcomes and associated factors of severe acute malnutrition among under-5 children in Jigjiga public hospitals, Somali region, Ethiopia: a retrospective cohort study. BMJ Public Health. 2025;3:e001737. doi:10.1136/bmjph-2024-001737

20 Adem F, Edessa D, Bayissa B, Mohammed Hassen M, A Mohammed M. Treatment Outcomes and Associated Factors in Hospitalised Children with Severe Acute Malnutrition: A Prospective Cohort Study. Pediatric Health Med Ther. 2020;Volume 11:235–43. doi:10.2147/phmt.s253396

21 Ahmad S, Ellis J, Nesbitt A, Molyneux E. Pericardial effusions in children with severe protein energy malnutrition resolve with therapeutic feeding: A prospective cohort study. Arch Dis Child. 2008;93:1033–6. Medline:18499774 doi:10.1136/adc.2007.136747

22 Ahmed N, Golwara S, Agrawal R, Kumar D, Singh BK. Co-Morbidities in Severe Acute Malnutrition, Including Unanticipated Dyselectrolytemia in Diarrhoea: An

Observational Study. Original Research Article International Journal of Pharmaceutical and Clinical Research. 2021;13:90–6. Available: www.ijpcr.com

23 Ahmed JA, Yusuf N, Wilfong T, Tukeni KN, Berhanu H, Roba KT. Treatment outcomes among children admitted stabilization centers in Eastern Ethiopia: retrospective study. Front Public Health. 2023;11. Medline:37533525 doi:10.3389/fpubh.2023.1165858

24 Anshuman. Clinico-Demographic Profile and Outcome Assessment of Complications in Children Presented with Severe Acute Malnutrition (SAM). International Journal of Current Pharmaceutical Review and Research Original Research Article. 2023;15:324–8. Available: http://www.budapestopenaccessinitiative.org/read

25 Asafo-Agyei SB, Antwi S, Nguah SB. HIV infection in severely malnourished children in Kumasi, Ghana: A cross-sectional prospective study. BMC Pediatr. 2013;13. Medline:24206638 doi:10.1186/1471-2431-13-181

26 Ashine YE, Ayele BA, Aynalem YA, Yitbarek GY. Time to Death and its Predictor Among Children Under Five Years of Age with Severe Acute Malnutrition Admitted to Inpatient Stabilization Centers in North Shoa Zone, Amhara Region, Ethiopia. Nutr Diet Suppl. 2020;12:167–77. doi:10.2147/nds.s249045

27 Asiimwe O, Ndezi G, Muhumuza J, Namukasa F, Mutisya CM, Abdirahman SH, et al. Prevalence, radio-clinical patterns and factors associated with pulmonary tuberculosis among children with severe acute malnutrition: a cross-sectional study in Uganda. J Health Popul Nutr. 2025;44. Medline:41107922 doi:10.1186/s41043-025-01107-7

28 Atalell KA, Haile RN, Techane MA. Magnitude of tuberculosis and its associated factors among under-five children admitted with severe acute malnutrition to public hospitals in the city of Dire Dawa, Eastern Ethiopia, 2021: multi-center cross-sectional study. IJID Regions. 2022;3:256–60. doi:10.1016/j.ijregi.2022.04.008

29 Aye A, Amare F, Sosengo T. Treatment outcomes and associated factors among children with severe acute malnutrition at Hiwot Fana Specialized University Hospital, Harar, Eastern Ethiopia: a retrospective cohort study. Sudan J Paediatr. 2023;32–41. doi:10.24911/sjp.106-1635757512

30 Aynalem YA, Getacher L, Ashene YE, Yirga Akalu T, Yideg Yitbarek G, Yeshanew Ayele F, et al. Incidence of tuberculosis and its predictors among under-five children with severe acute malnutrition in North Shoa, Amhara region, Ethiopia: a retrospective follow-up study. Front Pediatr. 2023;11. doi:10.3389/fped.2023.1134822

31 Banga D, Baren M, Ssonko NV, Sikakulya FK, Tibamwenda Y, Banga C, et al. Comorbidities and factors associated with mortality among children under five years admitted with severe acute malnutrition in the nutritional unit of Jinja Regional Referral Hospital, Eastern Uganda. International Journal of Pediatrics (United Kingdom). 2020;2020. doi:10.1155/2020/7809412

32 Baraki AG, Akalu TY, Wolde HF, Takele WW, Mamo WN, Derseh B, et al. Time to recovery from severe acute malnutrition and its predictors: A multicentre retrospective follow-up study in Amhara region, north-west Ethiopia. BMJ Open. 2020;10. Medline:32060161 doi:10.1136/bmjopen-2019-034583

33 Bello A, Abugi AA, Abdulmutallab A, Uhuami AO, Babazhitsu M, Adamu A, et al. Prevalence of Tuberculosis and Related Factors among Malnourished Under-Five Children in a Therapeutic Feeding Center, Specialist Hospital, Sokoto, Nigeria. 2025. doi:10.21203/rs.3.rs-6844447/v1

34 Bhat PG, Kumar AMV, Naik B, Satyanarayana S, Deepak KG, Nair SA, et al. Intensified tuberculosis case finding among malnourished children in nutritional rehabilitation centres of Karnataka, India: Missed opportunities. PLoS One. 2013;8. Medline:24358350 doi:10.1371/journal.pone.0084255

35 Bitew ZW, Alebel A, Worku T, Alemu A. Recovery rate and its predictors among children with severe acute malnutrition in Addis Ababa, Ethiopia: A retrospective cohort study. PLoS One. 2020;15. Medline:32701985 doi:10.1371/journal.pone.0235259

36 Bizuneh FK, Tolossa T, Bekonjo NE, Wakuma B. Time to recovery from severe acute malnutrition and its predictors among children aged 6–59 months at Asosa general hospital, Northwest Ethiopia. A retrospective follow up study. PLoS One. 2022;17. Medline:35960715 doi:10.1371/journal.pone.0272930

37 Chabala C, Roucher C, Ton Nu Nguyet MH, Babirekere E, Inambao M, Businge G, et al. Development of tuberculosis treatment decision algorithms in children below 5 years hospitalised with severe acute malnutrition in Zambia and Uganda: a prospective diagnostic cohort study. EClinicalMedicine. 2024;73:102688. Medline:39007063 doi:10.1016/j.eclinm.2024.102688

38 Chama GC, Siame L, Kapoma C, Hamooya BM, Masenga SK. Severe acute malnutrition among children under the age of 5 years. PLoS One. 2024;19. Medline:39186515 doi:10.1371/journal.pone.0309122

39 Clavier-Rogez S, Rogez JB, Labrin L, Branger B, Dabadie A. Évaluation d'un programme nutritionnel à base d'un aliment thérapeutique prêt à l'emploi au Tchad. Archives de Pediatrie. 2015;22:1247–55. Medline:26527501 doi:10.1016/j.arcped.2015.09.009

40 De Maayer T, Saloojee H. Clinical outcomes of severe malnutrition in a high tuberculosis and HIV setting. Arch Dis Child. 2011;96:560–4. Medline:21310895 doi:10.1136/adc.2010.205039

41 Desyibelew HD, Fekadu A, Woldie H. Recovery rate and associated factors of children age 6 to 59 months admitted with severe acute malnutrition at inpatient unit of Bahir Dar Felege Hiwot Referral hospital therapeutic feeding unite, northwest Ethiopia. PLoS One. 2017;12. Medline:28166247 doi:10.1371/journal.pone.0171020

42 Fedlu H, Fekadu L, Merera AM, Asafa K, Tiruneh F. Duration of recovery from severe acute malnutrition and associated factors in children aged 6–59 months: a retrospective cohort study. Sci Rep. 2026;16. Medline:41436503 doi:10.1038/s41598-025-28931-5

43 Fikrie A, Alemayehu A, Gebremedhin S. Treatment outcomes and factors affecting time-to-recovery from severe acute malnutrition in 6-59 months old children admitted to a stabilization center in Southern Ethiopia: A retrospective cohort study. Ital J Pediatr. 2019;45. Medline:30971316 doi:10.1186/s13052-019-0642-x

44 Gaurav A, Nishant A, Lipika M. International Journal of Toxicological and Pharmacological Research 145 Original Research Article In India, as National Family Health Survey (NFHS), prevalence of SAM has increased from 7. International Journal of Toxicological and Pharmacological Research. 2023;13. Available: http://www.budapestopenaccessinititative.org/read

45 Girma T, Kaestel P, Mølgaard C, Michaelsen KF, Hother A-L, Friis H. Predictors of oedema among children hospitalized with severe acute malnutrition in Jimma University Hospital, Ethiopia: a cross sectional study. 2013;13. Available: http://www.biomedcentral.com/1471-2431/13/204

46 Girum T, Kote M, Tariku B, Bekele H. Survival status and predictors of mortality among severely acute malnourished children <5 years of age admitted to stabilization centers in Gedeo Zone: a retrospective cohort study. Ther Clin Risk Manag. 2017;13:101–10. Medline:28176953 doi:10.2147/TCRM.S119826

47 Gupta R, Nagori G, Nagori P, Patidar R. Pattern of Co-morbidities in Children with Severe Acute Malnutrition admitted in MTC of a teaching hospital of South East Rajasthan, India. J Pharm Biomed Sci. 2015;05:403–7. Available: www.jpbms.info

48 Haider R, Tripathy S, Raza R. An Observational Research to Investigate the Spectrum of Co-Morbidities in Severe Acute Malnutrition Associated with Unexpected Dyselectrolytemia in Diarrhoea International Journal of Pharmaceutical and Clinical Research. Original Research Article Haider et al International Journal of Pharmaceutical and Clinical Research. 2021;13:487–92. Available: www.ijpcr.com

49 Hossain MI, Dodd NS, Ahmed T, Miah GM, Jamil KM, Nahar B, et al. Experience in managing severe malnutrition in a government tertiary treatment facility in Bangladesh. J Health Popul Nutr. 2009;27:72–80. Medline:19248650 doi:10.3329/jhpn.v27i1.3319

50 Hundiwala H, Bora B. Clinical Profile and Factors Influencing Recovery in Pediatric Severe Acute Malnutrition: An Institutional Cohort Study. Medico Research Chronicles. 2026;13:191–200. doi:10.26838/MEDRECH.2026.13.1.858

51 Ide LEY. Prevalence of Tuberculosis among Children with Severe Acute Malnutrition at Ola during Children's Hospital in Freetown Sierra Leone. J Adv Med Med Res. 2019;1–7. doi:10.9734/jammr/2019/v30i330179

52 Ikobah JM, Uhegbu K, Akpan F, Muoneke L, Ekanem E. Predictors of In-Patient Mortality of Severe Acute Malnutrition of Hospitalised Children in a Tertiary Facility in Southern Nigeria. Cureus. 2022. doi:10.7759/cureus.24195

53 Kabeta A, Bekele G. Factors Associated with Treatment Outcomes of Under-five Children with Severe Acute Malnutrition Admitted to Therapeutic Feeding Unit of Yirgalem Hospital. Clin Mother Child Health. 2017;14. doi:10.4172/2090-7214.1000261

54 Kabthymer RH, Gizaw G, Belachew T. Time to cure and predictors of recovery among children aged 6-59 months with severe acute malnutrition admitted in Jimma university medical center, southwest Ethiopia: A retrospective cohort study. Clin Epidemiol. 2020;12:1149–59. doi:10.2147/CLEP.S265107

55 Kachhwaha C, Malviya A, Nema M, Sahu S, Kachhwaha V. Screening Of Pulmonary Tuberculosis in Severe Acute Malnourished Children at Nutritional

Rehabilitation Centre of M.G.M. Medical College, Indore. European Journal of Cardiovascular Medicine. 2023;13:1465–72. doi:10.5083/ejcm

56 Kassaw A, Amare D, Birhanu M, Tesfaw A, Zeleke S, Arage G, et al. Survival and predictors of mortality among severe acute malnourished under-five children admitted at Felege-Hiwot comprehensive specialized hospital, northwest, Ethiopia: a retrospective cohort study. BMC Pediatr. 2021;21. Medline:33863303 doi:10.1186/s12887-021-02651-x

57 Khalil B, Hussain M, Taj W, Iqbal S, Irshad M, Khan MJ, et al. Frequency of Pulmonary Tuberculosis in Severely Acute Malnourished Children and its Association with Inappropriate Feeding Practices. J Med Sci. 2020;28:252–5.

58 Kumar P, Mishra K, Singh P, Rai K. Should we screen children with severe acute malnutrition for celiac disease? Indian Pediatr. 2012;49:330–1.

59 Kumar R, Singh J, Joshi K, Singh HP, Bijesh S, Singh P. Co-morbidities in Hospitalized Children with Severe Acute Malnutrition. Indian Pediatr. 2014;125.

60 Kumar S, Chaubey PK. An Observational Hospital Study of Severe Acute Malnutrition with Unanticipated Dyselectrolytemia in Diarrhoea and its Co-Morbidities. International Journal of Current Pharmaceutical Review and Research Original Research Article. 2023;15:395–8. Available: http://www.budapestopenaccessinitiative.org/read

61 Kumar B, Kumar R, Kumar A. Comorbidities and Electrolyte Imbalances in Children with Extreme Acute Malnutrition and Diarrhea: An Observational Study. International Journal of Current Pharmaceutical Review and Research Original Research Article. 2025;17:1034–8. Available: http://www.budapestopenaccessinitiative.org/read

62 Kyasa SB, Srinivas K. Study of Risk Factors for Severe Acute Malnutrition with Respect to Clinical and Demographic Profile. International Journal of Pharmaceutical and Clinical Research Original Research Article. 2024;16:169–74. doi:10.1136/bmjgh-2021

63 Lacourse SM, Chester FM, Preidis G, Mccrary LM, Arscott-mills T, Maliwichi M, et al. Use of Xpert® for the Diagnosis of Pulmonary Tuberculosis in Severely Malnourished Hospitalized Malawian Children. Pediatric infectious disease journal. 2014;33:1200–2. Medline:25361410 doi:10.1097/INF.0000000000000384.Use

64 Majid A, Shakir Hussain M, Najar BA, Hussain Tali S, Gulzar S. Clinical Profile and Outcome of Children with Severe Acute Malnutrition Associated at Nutritional Rehabilitation Center of MCCH-Associated Hospital of GMC-ANANTNAG. 2023;16:2023. doi:10.22159/ajpcr.2023v16i1.46306

65 Mekonnen C, Abebe M, Mosisa W. A retrospective cohort studying about time to recovery and its predictors among children aged 6–59 months admitted with severe acute malnutrition to inpatient therapeutic feeding centers at public hospitals in west Shoa Zone, Western Ethiopia.2022 G.C. Annals of Medicine & Surgery. 2025;87:541–54. doi:10.1097/ms9.0000000000002853

66 Mezemir M, Girma M, Bekele D. Treatment Outcome and Associated Factors of Acute Malnutrition Among Children in the Therapeutic Feeding Center of Public Hospitals in Addis Ababa, Ethiopia: An Institutional-Based Cross-Sectional Study. Pediatric Health Med Ther. 2022;Volume 13:145–54. doi:10.2147/phmt.s296979

67 Nambuya H, Mupere E, Nabukeera-Barung N, Mubiri P, Kamugisha JG, Rytter MJH, et al. Prevalence, incidence and associated factors of pneumonia among severely malnourished children hospitalized in Mulago National Referral Hospital, Uganda. PLoS One. 2017;9. doi:10.1371/journal.pone.0331698

68 Nasir M, Ahmed M, Abebaw E, Berhanu M, Birhanu B. Treatment outcomes and associated factors among infants under 6-Month-Old with severe acute malnutrition in Hawassa University Comprehensive Specialized Hospital, Southern Ethiopia. Ethiop Med J. 2023;61:249–58. Available: https://emjema.org/index.php/EMJ/article/view/2329

69 Nath PN, Kumar DS, Sankar RP. Clinical Profile and Outcome of Children of Aged 6-59 Months Admitted with Severe Acute Malnutrition at Medical College, Silchar, Assam. Medico-legal Update. 2020;20:1614–8.

70 Nienaber A, Dolman-Macleod RC, Conradie C, Lombard M. Associations between infectious diseases and clinical outcomes among children aged 6-59 months admitted for severe acute malnutrition: The SAMAC study. Clin Nutr ESPEN. 2024;63:1026. doi:10.1016/j.clnesp.2024.07.147

71 Osorio DV, Munyangaju I, Muhiwa A, Nacarapa E, Nhangave AV, Ramos JM. Lipoarabinomannan Antigen Assay (TB-LAM) for Diagnosing Pulmonary Tuberculosis in Children with Severe Acute Malnutrition in Mozambique. J Trop Pediatr. 2021;67. Medline:33038897 doi:10.1093/tropej/fmaa072

72 Oumer A, Mesfin L, Tesfahun E, Ale A. Predictors of death from complicated severe acute malnutrition in east ethiopia: Survival analysis. Int J Gen Med. 2021;14:8763–73. doi:10.2147/IJGM.S337348

73 Page AL, de Rekeneire N, Sayadi S, Aberrane S, Janssens AC, Rieux C, et al. Infections in Children Admitted with Complicated Severe Acute Malnutrition in Niger. PLoS One. 2013;8. Medline:23874731 doi:10.1371/journal.pone.0068699

74 Panda S, Ranjan Barik R, Bharaj D, Behera JR. Clinico-Biochemical Profile of Severe Acute Malnutrition with Special Reference to Infection. International Journal of Academic Medicine and Pharmacy (www.academicmed.org) Original Research Article Int J Acad Med Pharm. 2023;5. doi:10.47009/jamp.2023.5.6.80

75 Pathak SK, Kumar S. An Observational Research to Determine the Co-morbidities Associated with Severe Acute Malnutrition. International Journal of Pharmaceutical and Clinical Research. 2021;13:352–7. Available: www.ijpcr.com

76 Pathak K, Sivan AM. Clinicodemographic Profile, Risk Factors and Associated Co-morbidities in Children with Severe Acute Malnutrition: An Observational Study from a Tertiary Care Centre in Assam, India. Journal of Clinical and Diagnostic Research. 2026. doi:10.7860/JCDR/2026/81715.23146

77 Prabhakar S, Prajapati H, Prasad Mandal J, Shankar Sahni G. Etiological Factors, Clinical Presentation, and Outcomes among Children with Severe Acute Malnutrition (SAM): A Retrospective Study. International Journal of Pharmaceutical Quality Assurance. 2025;16. doi:10.25258/ijpqa.16.12.142

78 Radhan AH, Laghari GS, Shaikh SA, Chand S, Shah MA, Touseef M. Clinical Profile and Outcomes of Children Aged 6 to 59 Months Admitted to a Tertiary Care Hospital with Severe Acute Malnutrition. Med Forum. 2021;32:132.

79 Sahay BP, Irfan A, Bhushan S. To Assess the Range Comorbidities in Severe Acute Malnutrition Accompanied by Unexpected Electrolyte Imbalances during

Episodes of Diarrhoea. International Journal of Current Pharmaceutical Review and Research Original Research Article. 2024;16:348–52. Available: http://www.budapestopenaccessinitiative.org/read

80 Sathenahalli VB, Minarey N, Gornale V, Kumar R, Joshi K, H P S. Association of Tuberculosis with Severe Acute Malnutrition. J Evol Med Dent Sci. 2015;4:11865–70. doi:10.14260/jemds/2015/1710

81 Singh AR, Kumar A, Shewade HD, Dhingra B. Poor adherence to TB diagnosis guidelines among under-five children with severe acute malnutrition in central India: A missed window of opportunity? PLoS One. 2021;16. Medline:33711040 doi:10.1371/journal.pone.0248192

82 Solanki TK, Singh Kushwaha V, Kumar V, Bhalerao VP. Children with Severe Acute Malnutrition: Clinical Features and Associated Co-morbidities. International Journal of Current Pharmaceutical Review and Research Original Research Article. 2025;17. Available: http://www.budapestopenaccessinitiative.org/read

83 Thakur J, Thakur R, Bhatta NK, Yadav SP, Khanal B, Bhattarai NR. Prevalence of Tuberculosis in Severe Acute Malnutrition: A Prospective Observational Study. Journal of Nepal Paediatric Society. 2022;42:108–11. doi:10.3126/jnps.v42i1.39974

84 Thapa A, Shah GS, Mishra OP. Analysis of co-morbidities in children with severe acute malnutrition in Eastern Nepal. Journal of Nepal Paediatric Society. 2015;35:99–102. doi:10.3126/jnps.v35i2.13098

85 Thomas A, Engelbrecht AL, Slogrove AL. Severe acute malnutrition outcomes for children of South African compared to foreign-born parents admitted to a rural regional hospital in South Africa: a retrospective cohort study. J Trop Pediatr. 2022;68. Medline:36350713 doi:10.1093/tropej/fmac097

86 Vonasek BJ, Nyirongo M, Chetcuti K, Chiunda M, Kamvaunamwali T, Kaphatika J, et al. High prevalence of TB in children less than 5 years old hospitalised with severe acute malnutrition. The International Journal of Tuberculosis and Lung Disease. 2026;30:180–2. Medline:41896713 doi:10.5588/ijtld.25.0492

87 Wagnew F, Dejenu G, Eshetie S, Alebel A, Worku W, Abajobir AA. Treatment cure rate and its predictors among children with severe acute malnutrition in northwest Ethiopia: A retrospective record review. PLoS ONE. Public Library of Science; 2019. Medline:30785917 doi:10.1371/journal.pone.0211628

88 Wake AD. Survival Status and Predictors of Tuberculosis Development Among Under 5 Children Admitted With Severe Acute Malnutrition in Ethiopia: A Retrospective Cohort Study. Glob Pediatr Health. 2024;11. doi:10.1177/2333794X231226071

89 Wondim A, Tigabu B, Kelkay MM. Time to Recovery from Severe Acute Malnutrition and Its Predictors among Admitted Children Aged 6-59 Months at the Therapeutic Feeding Center of Pawi General Hospital, Northwest Ethiopia: A Retrospective Follow-Up Study. International Journal of Pediatrics (United Kingdom). 2020;2020. doi:10.1155/2020/8406597

90 Sinha P, Lönnroth K, Bhargava A, Heysell SK, Sarkar S, Salgame P, et al. Food for thought□: addressing undernutrition to end tuberculosis. Lancet Infectious Diseases. 2021;online fir. doi:10.1016/S1473-3099(20)30792-1

91 Graham SM, Ahmed T, Amanullah F, Browning R, Cardenas V, Casenghi M, et al. Evaluation of tuberculosis diagnostics in children: 1. Proposed clinical case definitions for classification of intrathoracic tuberculosis disease. Consensus from an expert panel. J Infect Dis. 2012;205 Suppl 2:S199-208. Medline:22448023 doi:10.1093/infdis/jis008

92 Graham SM, Cuevas LE, Jean-Philippe P, Browning R, Casenghi M, Detjen AK, et al. Clinical case definitions for classification of intrathoracic tuberculosis in children: an update. Clinical Infectious Diseases. 2015;61:S179–87. Medline:26409281 doi:10.1093/cid/civ581

Figure Legends

Figure 1. PRISMA flow diagram of study selection.

Figure 2. Forest plot of meta-analysis of the prevalence of tuberculosis in children with severe acute malnutrition for all included studies. CI: confidence interval.

Supplementary Figures

Figure S1. Forest plot of meta-analysis of the prevalence of tuberculosis in children with severe acute malnutrition with studies stratified by United Nations geoscheme subregion. CI: confidence interval.

Figure S2. Forest plot of meta-analysis of the prevalence of tuberculosis in children with severe acute malnutrition with studies stratified by quality. CI: confidence interval.

Figure S3. Forest plot of meta-analysis of the prevalence of tuberculosis in children with severe acute malnutrition with studies stratified by national tuberculosis annual incidence (low: <150 per 100,000; medium: 150 to 250 per 100,000; high: >250 per 100,000). CI: confidence interval.

Figure S4. Forest plot of meta-analysis of the prevalence of tuberculosis in children with severe acute malnutrition—sub-group analysis by HIV status. CI: confidence interval.

Figure S5. Forest plot of meta-analysis of the prevalence of tuberculosis in children with severe acute malnutrition—sub-group analysis by presence or absence of history of exposure to an individual with tuberculosis. CI: confidence interval.

Figure S6. Forest plot of meta-analysis of the prevalence of tuberculosis in children with severe acute malnutrition—sub-group analysis by age. CI: confidence interval.

Figure S7. Forest plot of meta-analysis of the prevalence of tuberculosis in children with severe acute malnutrition—sub-group analysis by sex. CI: confidence interval.

Figure S8. Forest plot of meta-analysis of the prevalence of tuberculosis in children with severe acute malnutrition—sub-group analysis by presence or absence of nutritional edema. CI: confidence interval.

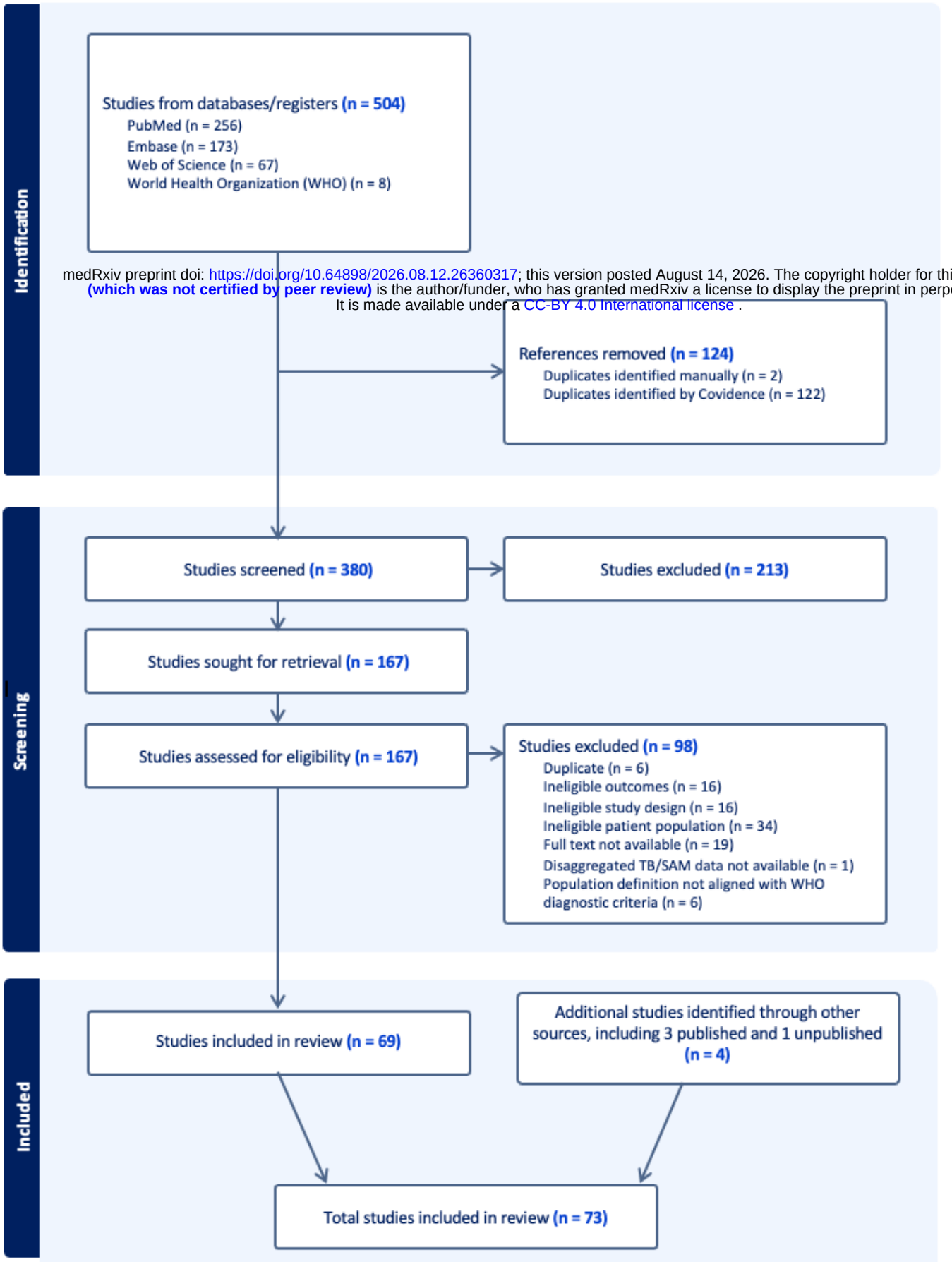

Figure 1. PRISMA flow diagram of study selection.

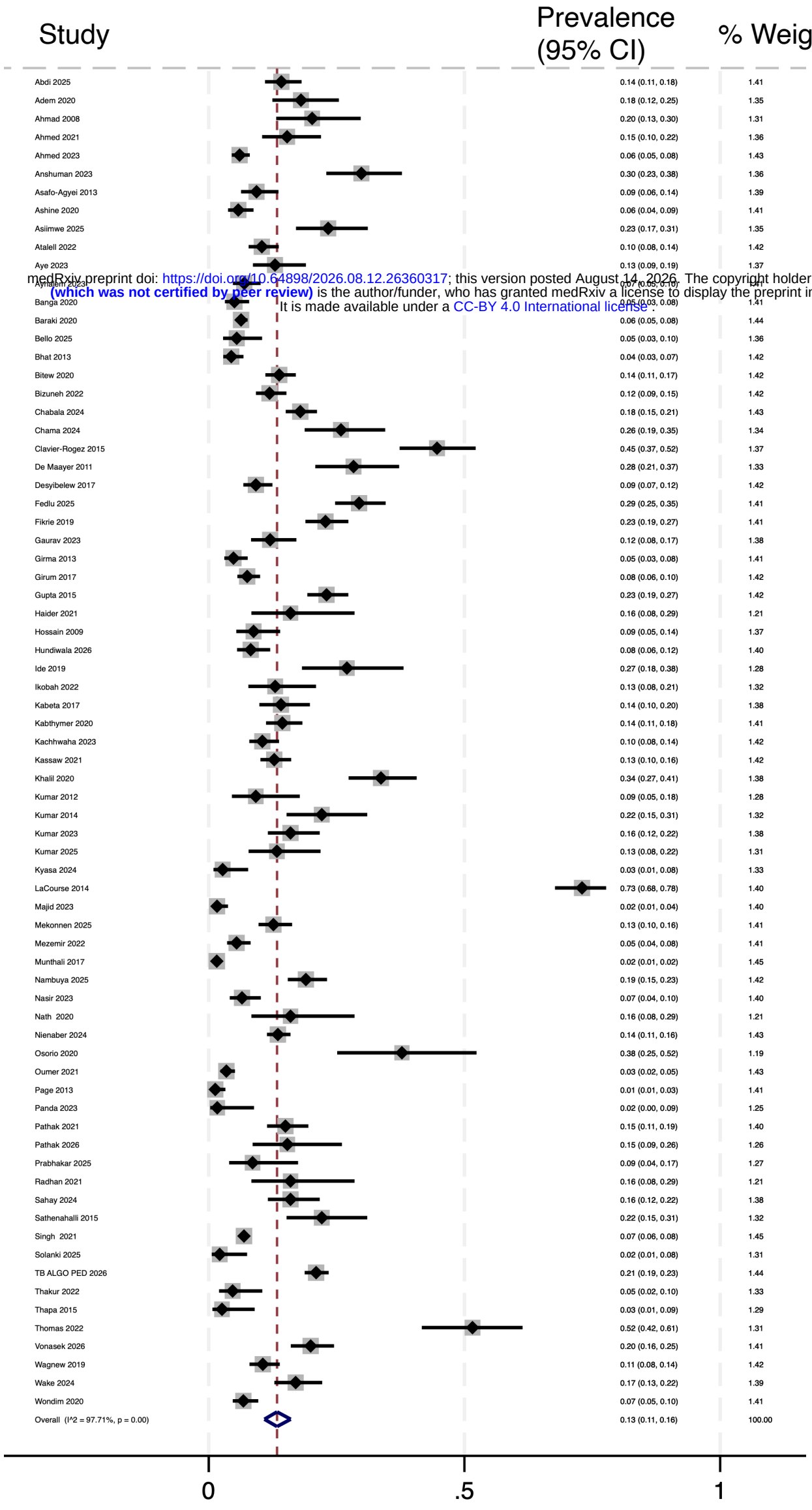

Figure 2. Forest plot of meta-analysis of the prevalence of tuberculosis in children with severe acute malnutrition for all included studies. CI: confidence interval.