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SYSTEMATIC REVIEW

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Burden of pertussis in infants in the Eastern Mediterranean Region and the impact of maternal vaccination: a systematic review

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Abstract

Background Despite vaccine availability, Pertussis remains a global public health challenge, especially among infants. The Eastern Mediterranean Region (EMR) presents a diverse epidemiological landscape with varying vaccination coverages and healthcare infrastructures. This systematic review aimed to assess the burden of pertussis in infants < 1 year of age in the EMR and evaluate the use and impact of pertussis vaccination during pregnancy.

Methods Following PRISMA guidelines, we conducted a systematic search of Scopus, Embase, CINAHL Ultimate, and PubMed from inception until April 30, 2024. Studies included reported on pertussis burden in infants or maternal vaccination. Data extraction and quality assessment were performed in duplicate, focusing on incidence, age distribution, disease severity, and vaccination uptake and impact when data were available.

Results Thirty-six studies were included, the majority from Iran (*N* = 11), Morocco (*N* = 5), Tunisia (*N* = 5), and Oman (*N* = 3), with underrepresentation of other EMR countries. The incidence of PCR-confirmed pertussis among children with suspected pertussis varied significantly, from 6.7% to 8.9% (Morocco 2018–2019) to 50.4% and 51.6% (Palestine 2004–2008) among children < 12 and < 6 months, respectively, and between 16.3% (Tunisia 2007–2016) to 73.0% (Morocco 2013–2015) in children < 2 months. Age distribution data indicated the highest burden was in infants < 2 months regardless of the population studied. High hospitalization rates and severe complications, including seizures and the need for ventilatory support, were frequently reported in infants < 6 months of age. Only one study from Saudi Arabia addressed maternal pertussis vaccination, reflecting low vaccine uptake and awareness among pregnant women.

Conclusions This review underscores the substantial burden of pertussis among infants in the EMR and the lack of data on maternal immunization. The findings emphasize the need for enhanced surveillance and targeted public health interventions to reduce disease incidence. Future research should prioritize underrepresented countries to ensure comprehensive data for informed public health strategies.

Trial registration PROSPERO (CRD42024573471)

Keywords Pertussis, Eastern Mediterranean Region, Infants, Maternal vaccination, Tdap, Systematic review, Vaccine

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Background

Pertussis, commonly known as whooping cough, remains a significant public health challenge globally despite the availability of vaccines for over half a century [1, 2]. The disease, caused by the bacterium *Bordetella pertussis*, is particularly severe in infants, who are at high risk of complications, hospitalization, and death [1]. Recent studies continue to highlight the resurgence of pertussis in many parts of the world, including regions with high vaccination coverage [3–5], underscoring the need for ongoing surveillance and vaccination efforts.

Maternal vaccination against pertussis during pregnancy has been recommended by experts [6] and implemented in several countries to protect infants in their first months of life before they are eligible for their own vaccinations [7, 8]. This strategy leverages the transfer of maternal antibodies to the fetus, providing early protection against pertussis. Studies have demonstrated the significant effectiveness of maternal vaccination in preventing around 70–90% of pertussis disease, up to 91% of pertussis hospitalizations, and 95% of pertussis-associated deaths in young infants < 3 months of age [9].

Despite the proven benefits of maternal pertussis vaccination, its implementation in the Eastern Mediterranean Region (EMR), has been limited. The EMR is characterized by diverse socioeconomic and healthcare systems, varying levels of vaccination coverage, and differing epidemiological patterns of infectious diseases [10, 11]. It faces unique challenges, including weak healthcare infrastructure, limited access to healthcare services in certain areas, and differing levels of public health awareness [10–12]. The COVID-19 pandemic has further strained healthcare resources and disrupted routine vaccination programs, potentially affecting pertussis control efforts [13].

The burden of pertussis among infants in the EMR and the impact of maternal vaccination on infant pertussis outcomes have not been systematically reviewed. Understanding the epidemiological patterns of pertussis and evaluating the effectiveness of preventive strategies, such as maternal vaccination, are crucial for informing public health policies and interventions in this region. This systematic review aims to address two primary objectives: [1] to assess the burden of pertussis in infants under one year of age in the EMR, including measures such as prevalence, incidence, disease severity, complications, mortality, and economic impact, and [2] to evaluate the extent to which maternal pertussis vaccination is utilized during pregnancy, including variations in coverage and uptake, and its effects on key infant pertussis outcomes such as disease prevention, severity reduction, and associated health care costs. By synthesizing available data, this study seeks to provide a comprehensive understanding of pertussis epidemiology in the EMR and inform future public health strategies to combat this preventable disease.

Methods

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Guidelines (see Additional file 1). The protocol for this systematic review is published on PROSPERO (CRD42024573471).

Literature search

We conducted a systematic search in Scopus, Embase, CINAHL Ultimate, and PubMed covering studies published from the earliest date available in each database until 30 April 2024. The search string was developed and adapted based on the two primary objectives of this study. The search string was further tailored to suit the specific requirements of each database. We used MeSH terms and relevant keywords related to pertussis, infants, burden of disease, pertussis vaccination, pregnant women, and the World Health Organization (WHO) list of countries in the EMR (see Additional file 2). Additionally, we reviewed the reference lists of included studies and topic-related reviews. We did not restrict our search to specific languages.

Study selection

Pairs of reviewers screened citations and abstracts, and full texts, in duplicates and independently, using a predefined screening guide. Reviewers conducted a calibration exercise by piloting a sample of 20 abstracts and full-text articles and by comparing their results. If the discrepancy rate was > 5%, the reviewers examined the discordant documents and with the advice of a content expert, modified the screening guide to ensure standardization of the screening process. Reviewers repeated the calibration exercise until achieving > 95% concordance rate.

For objective 1, we included studies involving infants under one year of age in the EMR who were diagnosed with pertussis (either clinically or through laboratory testing) and reported at least one measure of pertussis burden, such as prevalence, incidence, disease severity, complications, mortality, or economic impact (including direct healthcare costs like hospitalizations, medications, and doctor visits). We excluded studies that only focused on patients over one year of age or did not have confirmed pertussis diagnoses.

For objective 2, we included studies on mothers in the EMR who received pertussis vaccination at any point during their pregnancy and reported at least one outcome related to infant pertussis or the uptake rate or effects of the vaccine. We excluded studies that focused only on mothers who did not receive pertussis vaccination during pregnancy or did not correlate pertussis vaccination during pregnancy with pertussis disease or vaccine outcomes.

For information on excluded studies and the reasons for their exclusion, refer to Additional file 3.

Data extraction

Two reviewers independently and in duplicate, abstracted data on study characteristics, including study design, period, setting, recruitment and sampling procedures, and inclusion criteria (e.g., case definition, sample size). Data extraction was tailored to align with the study's two primary objectives:

1. **Assessing the burden of pertussis in infants**: Data extracted included measures such as the number and frequency of confirmed pertussis cases (overall, by age, and by vaccination status), rate of complications (hospitalization, hospital stay duration, need for intensive care, seizures, ventilatory support, and death), and other relevant indicators like disease severity and economic impact. Information on population baseline characteristics (e.g., age, sex, and vaccination status) and confirmatory laboratory methods was also recorded to provide context to the burden estimates. Where available, information on antibiotics administered before sampling and population characteristics relevant to vaccination status was also captured.
2. **Evaluating the impact and pattern of maternal vaccination use**: Extracted data included maternal vaccination coverage rates, timing of vaccine administration during pregnancy, and maternal vaccination uptake. Outcomes assessed included the effect of vaccination on infant pertussis cases, complications, and severity.

Additionally, information on conflicts of interest and funding sources was extracted to ensure a comprehensive evaluation of study quality and reliability.

Quality assessment

Two reviewers assessed the risk of bias in duplicate and independently, using the Newcastle-Ottawa Quality Assessment Scale (NOS) for cohort studies [14]. The NOS evaluates studies based on three domains: Selection, Comparability, and Outcome/Exposure. Each domain has a set of criteria that are scored to a maximum of nine stars: Selection (up to 4 stars), Comparability (up to 2 stars), and Outcome/Exposure (up to 3 stars). To categorize the studies into good, fair, and poor quality, we applied the following thresholds for converting NOS scores to Agency for Healthcare Research and Quality standards:

- Good: 3 or 4 stars in the Selection domain AND 1 or 2 stars in the Comparability domain AND 2 or 3 stars in the Outcome/Exposure domain.
- Fair: 2 stars in the Selection domain AND 1 or 2 stars in the Comparability domain AND 2 or 3 stars in the Outcome/Exposure domain.
- Poor: 0 or 1 star in the Selection domain OR 0 stars in the Comparability domain OR 0 or 1 star in the Outcome/Exposure domain.

In addition to the NOS, the quality of cross-sectional and surveillance studies was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklists for Cross-Sectional Studies [15] and Prevalence Studies [16]. These JBI tools provided a systematic framework for appraising studies' validity, reliability, and overall relevance, ensuring that the conclusions drawn were grounded in high-quality evidence. For this review, we applied the following thresholds to categorize studies:

- **Good**: Studies that received a "Yes" response for at least 80% of the applicable criteria.
- **Fair:** Studies that received a "Yes" response for 60–79% of the applicable criteria.
- **Poor:** Studies that received a "Yes" response for less than 60% of the applicable criteria.

We performed a calibration exercise among reviewers, as conducted for the screening process, until reaching a concordance rate of > 95% between reviewers. The results of the quality assessment are summarized in Additional file 4.

Data analysis

We organized the incidence data from each study based on age groups: < 12 months, < 6 months, and < 2 months. Additionally, we aggregated the age distribution of pertussis cases for < 12 months, < 6 months, < 3 months, and < 2 years. For each study, we calculated summary statistics for each age group and vaccination status where appropriate. We standardized incidence rates and age distributions to common metrics to ensure comparability across studies. This included converting reported percentages to absolute numbers or vice versa, as needed, and ensuring consistency in the units of measurement used across different studies.

To synthesize the results, we used a narrative synthesis approach. This method was chosen because it allows for the inclusion and comparison of studies with diverse methodologies and reporting standards, which is essential given the varied nature of the data. We tabulated the results of individual studies in summary tables, which included key variables such as incidence rates, age distribution, disease severity, complications, and vaccination status to allow for a structured comparison of data across studies. Due to the heterogeneity in how the results were reported in each study, a meta-analysis was not feasible. Instead, we grouped studies by country, type of study, population studied, method of diagnosis, and age distribution and vaccination coverage to explore possible causes of heterogeneity among study results.

Results

Search results

A total of 36 studies met the inclusion criteria: 35 studies evaluated the epidemiological burden of pertussis in infants in the EMR (Objective 1), and one study reported on the use of maternal vaccination against pertussis within the same region (Objective 2) (Fig. 1).

Characteristics of included studies

The majority ($n=11$) of the 35 included studies on the epidemiological burden of pertussis in infants used a prospective design. Among these, nine were hospital-based, one was community-based, and one was data-registry-based. Additionally, 10 studies were retrospective hospital or clinic-based studies. Furthermore, eight were country or province-wide surveillance studies, two of which represented the same cohort from Iran, and the remaining eight used a hospital-based cross-sectional design (Table 1).

The included studies represented twelve EMR countries. Iran was the most represented with 11 studies [17–27], followed by Morocco [28–32] and Tunisia [33–37] with five studies each, and Oman with three studies [38–40]. Saudi Arabia [41, 42], Pakistan [43, 44], and Iraq [22, 45, 46] each had two studies, and there was one study from each of Jordan [47], Palestine [48], Sudan [49], Syria [50], and Egypt [45].

The majority of studies focused on patients with suspected pertussis or pertussis-like syndrome (PLS) [17–25, 27–31, 33, 34, 43, 45, 48–50], using the WHO criteria to define clinical or suspected pertussis. While the review targeted infants under one year, several included studies presented broader age ranges that incorporated this target group. Two studies included hospitalized and non-hospitalized individuals with confirmed pertussis [41, 46], and another two included hospitalized children with confirmed pertussis [35, 38]. In addition, two country-wide surveillance studies [26, 40] and one retrospective study [39] included patients with probable and confirmed pertussis. One study followed healthy infants [44], while five studies evaluated hospitalized children with community-acquired pneumonia (CAP) [51], confirmed viral respiratory tract infection [42], fever and/or respiratory symptoms [47], severe acute respiratory failure [37], or individuals of all ages hospitalized with symptoms indicative of respiratory infections [32]. Most studies reported a predominance of males, with only seven studies reporting more than 50% of females in their population [27, 32, 35, 37, 39, 45, 50].

The included studies used various methods to confirm B. pertussis infection. More than half used polymerase chain reaction (PCR) ($N=19$) [18, 20, 22, 28–38, 42, 44, 47, 48, 51], one study relied on culture and/or PCR [39], seven studies considered any positive result by either culture or PCR as confirmation [19, 23–26, 40, 41], three studies relied solely on culture [17, 27, 45], and another relied on culture followed by PCR [43]. Three studies from Iran [21], Syria [50], and Sudan [49] relied only on clinical diagnosis. Additionally, one study relied on serodiagnosis by recognizing "Pertussis-specific IgM" in serum samples [46].

Nine studies reported antibiotic use by some or all of the population at presentation or before completion of the sampling [18, 19, 22, 29, 30, 33, 34, 36, 47]. An additional five studies reported antibiotic use by patients; however, they did not specify the timing of administration in relation to the sampling [17, 24, 31, 35, 38].

In 2023, a cross-sectional hospital-based study was conducted in the Taif region of Saudi Arabia, representing the only identified study focusing on maternal vaccination against pertussis in the EMR [52]. To our knowledge, this is the only study on mothers in the EMR who received pertussis vaccination at any point during their pregnancy. The study included 401 pregnant women over the age of 18 and aimed to assess their knowledge and acceptance of the pertussis vaccine during pregnancy, which was introduced into the national immunization program in Saudi in June 2019 [52]. Additionally, it aimed to determine the proportion of women who were vaccinated during pregnancy [52]. The majority of the sampled women (57.4%) were highly educated and unemployed housewives (73.1%). Most were in their third trimester of pregnancy (57.1%), while 27.2% and 15.7% were in their second and first trimesters, respectively [52].

No studies included data on the economic impact of pertussis in infants, such as direct healthcare costs (hospitalizations, medications, and doctor visits). While economic outcomes were part of the selection criteria, no relevant data were identified during the review.

The majority of studies were of good quality, with only five rated as fair quality [17, 22, 44, 46, 49], and two as poor quality [25, 42]. The main reasons for low-quality scores included the lack of an appropriate approach and

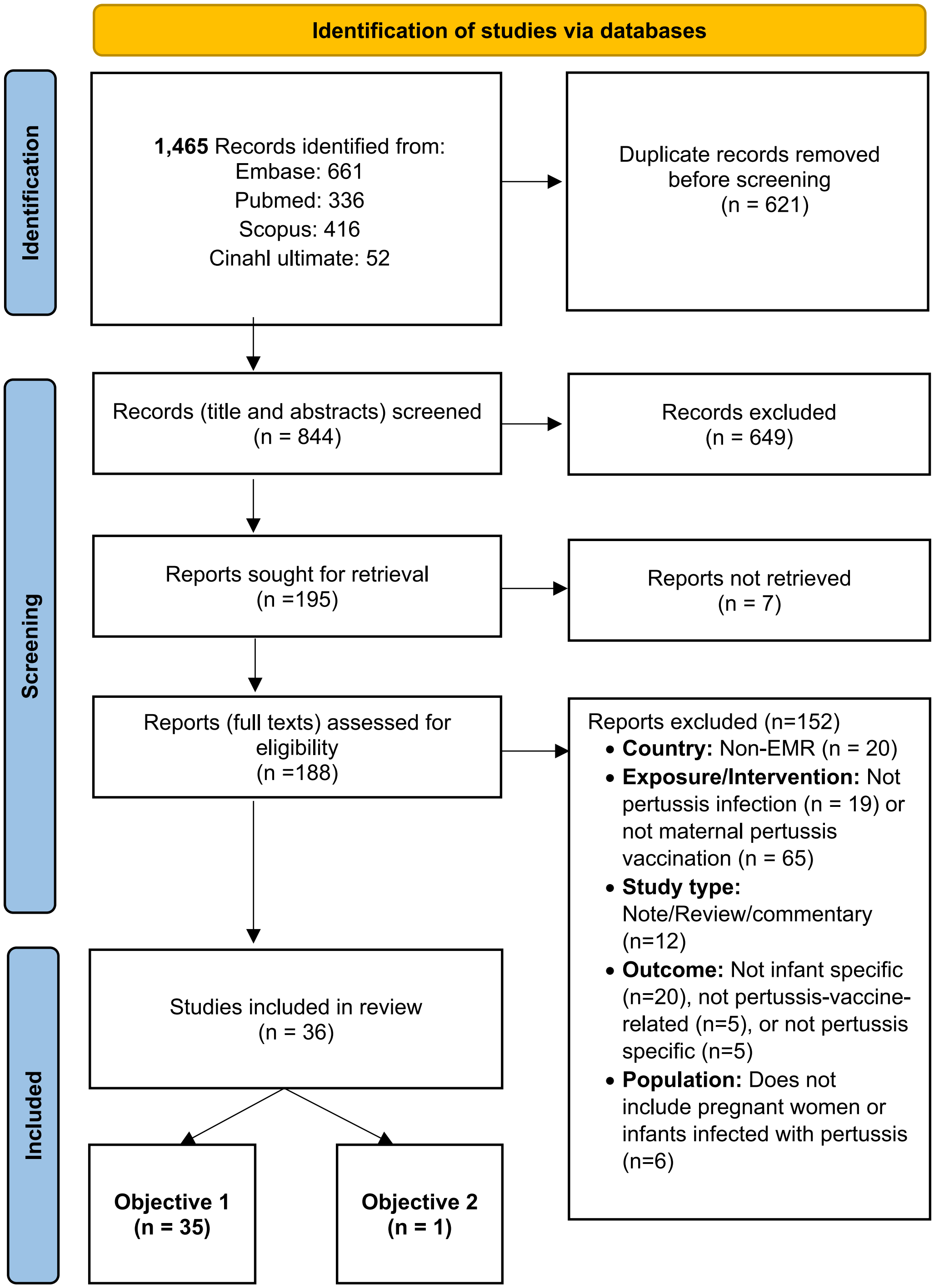

Fig. 1 Flow diagram of study selection

statistical analysis to address confounders, reliance on clinical diagnosis without confirmatory tests, and lack of clarity regarding the completeness of data collected. Details on the quality assessment are provided in Additional file 4.

Additionally, the majority of studies reported no conflict of interest, five did not mention conflict of interest [17, 22, 23, 27, 37, 45, 49], and only one reported that one of the authors is an editorial board member of the journal, but they took measures to exclude him from the

Table 1 Characteristics of included studies on pertussis epidemiologic burden in infants in the Eastern Mediterranean Region

Author, study design, period	Population case definition	Sample size	Age group N (%)	Females N (%)	Vaccination status N (%)	Anti-biotic use prior to sampling N (%)	Naso-pharyn-geal [A] sample testing using	Quality
Egypt								
N.R. Basha et al. [51], Cross-sectional hospital-based (2 hospitals), Aug 2015-Sept 2017	Children aged 2mo-12y, with clinical diagnosis of CAP (cough or difficult breathing and RR ≥ 60 bpm for children < 2 mo; ≥50 bpm for children 2–11 mo; ≥40 bpm for children). Hospitalized	400	Mean ± SD: 13.8 ± 15.5 mo Range: 2–84 mo • ≤ 4 mo: 104 (26.0) • 4–59 mo: 272 (68.0) • > 59 mo: 24 (6.0)	140 (35.0)	Incomplete vaccination: 200 (50)	NA	PCR[B]	Good
Iran								
A. Shamsizadeh et al. [18], Cross-sectional hospital-based (1 hospital), Jul 2018-Jul 2019	Children < 5y with PLS (Cough for > 14d with ≥ 1 symptom: Whoop and paroxysmal cough, apneic paroxysm, or posttussive vomiting; or coughs for > 21 d without the symptoms). Hospitalized	45	Mean ± SD: 3.2 ± 2.5 mo	17 (37.8)	NA	28 (62.2)	PCR	Good
G. Noel et al. [19], Prospective hospital-based study (2 hospitals), Nov 2016-May 2019	Infants ≤ 6 mo with PLS (Cough for ≥ 5d with ≥ 1 symptom: apnea, inspiratory "whooping," or posttussive vomiting; or persistent cough and a confirmed case of whooping cough in the entourage). Mostly hospitalized	199	Median (IQR): 2.0 (1.3–2.8) mo Range: 8 d-6 mo • < 3 mo: 157 (79.9) • ≥ 3 mo: 42 (21.1)	84 (42.8)	Vaccinated: 73 (36.7)	127 (63.8)	Culture or PCR	Good
Y. Alimohamadi et al. [20, 21], Countrywide surveillance, Feb 2012-Mar 2018	Individuals with PLS (Cough for ≥ 2 wks with ≥ 1 symptom: paroxysms (fits) of coughing, inspiratory whooping, posttussive vomiting, or vomiting without other apparent cause and apnea [only in < 1y of age]), registered in the department of vaccine-preventable diseases in the Iranian CDC at the MoH. Hospitalization status NA	7775	Mean ± SD: 6.3 ± 19.0 y • ≤ 1y: 4,838/7679 (63.0) • > 1y: 2,841/7679 (37.0)	3,714 (47.9)	NA	NA	PCR	Good
S. Mahmoudi et al. [22], Cross-sectional hospital-based (one hospital), Aug 2014-Aug 2015	Children < 2 y with clinical pertussis (Cough > 2 wks with ≥ 1 symptom: paroxysm of a cough, or inspiratory whoop, or posttussive vomiting, or apnea [with or without cyanosis]). Hospitalized	100	Mean ± SD: 5.5 ± NA mo • 0–2mo: 34 (34.0) • 2–4mo: 20 (20.0) • 4–6mo: 12 (12.0) • 6–18mo: 20 (20.0) • ≥ 18mo: 4 (4.0)	44 (44.0)	• Vaccinated: 66 (66.0) • Unvaccinated: 34 (34.0). All ≤ 2 mo	80 (80)	PCR	Fair

Table 1 (continued)

Author, study design, period	Population case definition	Sample size	Age group *N* (%)	Females *N* (%)	Vaccination status *N* (%)	Anti-biotic use prior to sampling *N* (%)	Naso-pharyn-geal [A] sample testing using	Quality
G. Ghorbani et al. [23], Countrywide surveillance, 2011–2013	Individuals with PLS (Cough of > 2 wks and ≥ 1 symptom: paroxysmal coughing, inspiratory whoop, or posttussive vomiting) reported to the pertussis surveillance system managed by the CDC, MoH. Hospitalization status NA	3629	• < 2 mo: 939 (25.9) • 2-11mo: 1335 (36.8) • 1–5 y: 467 (12.9) • 6–10 y: 348 (9.6) • > 10 y: 540 (14.9)	1759 (48.5)	NA	NA	Culture or PCR	Good
J. Shojaei et al. [24], Retrospective hospital-based study (one hospital), Mar 2008-Apr 2012	Infants < 12 mo with probable pertussis, whooping cough, pertussis syndrome, pertussis-link cough illness (Acute cough lasting ≥ 14-d with ≥ 1 pertussis-associated symptom: paroxysmal cough, inspiratory whoop, and posttussive vomiting without any obvious cause. Any afebrile coughing illness lasting ≥ 7-d and associated with paroxysm, whoop, facial discoloration during coughing episodes, or apnea as a presenting symptom or as a post-paroxysmal event (irrespective of duration) in infants < 6 mo). Hospitalized	118	• < 6 mo: 83 (70.3) • 6–12 mo: 35 (29.7)	60 (50.8)	Fully vaccinated: 26 (22.0)	118 (100) Timing NA	Culture or PCR	Good
M. Bahri et al. [27], Cross-sectional hospital-based (one hospital), Apr 2008 -Jul 2012	Children < 14y with clinical pertussis (Cough for > 2 wks, with wheezing and vomiting, and no other disease that could justify their prolonged cough, or patients who had been in contact with known pertussis patients in the past 3 mo and had apnea) at the Mazandaran Buali Sina Sari Educational-Treatment Hospital. Hospitalized	156	Mean ± SD: 15.8 ± 1.9 months Range 12dy-12y • ≤ 2mo: 60 (38.4) • > 2 mo: 96 (61.5)	89 (57.1)	• Vaccinated: 96 (61.5) • Unvaccinated: 60 (61.5). All ≤ 2 mo	NA	Culture	Good

Table 1 (continued)

Author, study design, period	Population case definition	Sample size	Age group *N* (%)	Females *N* (%)	Vaccination status *N* (%)	Anti-biotic use prior to sampling *N* (%)	Naso-pharyn-geal [A] sample testing using	Quality
M. Saffar et al. [26], Countrywide surveillance, 2008–2011	Probable pertussis (Cough for ≥ 14d with ≥ 1 symptom: spasmodic coughing, inspiratory whoop, and or posttussive vomiting without other obvious causes. Any afebrile infant < 6 mo with paroxysmal cough lasting ≥ 7 d associated with facial cyanosis or apnea diagnosed by a physician) and confirmed pertussis cases reported to P-CDC affiliated to Mazandaran University of Medical Sciences, Sari. Hospitalization status NA	518	Range: 0 mo-25 y < 6 mo: 185 (35.7)	NA	• Fully vaccinated: 282 (54.4) • Unvaccinated: 20 (3.8) • Unknown: 31 (8) • Not fully vaccinated: 185 (35.7). All < 6 mo	NA	Culture or PCR	Good
M. Hajia et al. [25], Countrywide surveillance, Oct 2008-Mar 2011	Infants < 6 mo suspected to have whooping cough and referred from physicians or other private clinical laboratories to the Research Center and Health Reference Laboratory, Ministry of Health and Medical Education, Tehran. Hospitalized and none hospitalized.	138	< 6 mo: 138 (100)	45 (32.6)	NA	NA	Culture or PCR	Poor
F. Shahcheraghi et al. [17], Countrywide surveillance, 2009–2010	Individuals suspected of having whooping cough (persistent cough lasting > 2 wks) from various provinces of Iran. Hospitalization status NA.	1084	• < 2 mo: 152 (14.0) • 2 mo-2 y: 586 (54.1) • 2–10 y: 157 (14.5) • > 10 y: 111 (10.2) • Unknown: 78 (7.2)	Positive cases: 5 (41.7)	Vaccinated: 693 (63.9) N (%) vaccinated by age group: • < 2mo: 0 • 2 mo-2 y: 487 • 2–10 y: 143 • > 10 y: 63 • Unknown: 89	826 (76.2) Timing NA	Culture	Fair
Iraq								
E. Mohammed Abdullah et al. [46], Province-wide surveillance, 2009–2019	Individuals with confirmed (confirmed by at least 2 specialized practitioners in internal medicine and pediatrics according to the standard criteria of the WHO) registered in public and private hospitals, including pediatrician private doctors in Anbar province. Hospitalized and non-hospitalized	608	Mean ± SD: 11.1 ± 3.0 y	293 (48.2)	NA	NA	Serodiagnosis - Pertussis-specific IgM in serum sample	Fair

Table 1 (continued)

Author, study design, period	Population case definition	Sample size	Age group N (%)	Females N (%)	Vaccination status N (%)	Anti-biotic use prior to sampling N (%)	Naso-pharyn-geal [A] sample testing using	Quality
K. Al-Bargish [45], Cross-sectional hospital-based (one hospital), Jun 1996 -Dec 1996	Clinical cases (Cough for ≥ 2 wks with ≥ 1 symptom: paroxysmal cough, inspiratory whoop, posttussive vomiting, early diagnosis of an epidemiological link to pertussis) referred from outpatient clinics or private clinics to the Department of Microbiology, College of Medicine Teaching Hospital or were inpatients at the Pediatric Hospital or the Teaching Hospital in Basra. Most hospitalized.	133	≤ 1 y: 35 (26.3)	98 (73.7)	Vaccinated: 95 (71.4%)	NA	Culture	Good
Jordan								
M. Jayyosi et al. [47], Prospective hospital-based study (one hospital), 2010–2012	Jordanian children < 2 y, with fever and/or respiratory symptoms. Hospitalized	420	Mean ± SD: 5.8 ± NA	177 (42.2)	NA	157 (37.3)	PCR	Good
Morocco								
R. Bennai et al. [32], Retrospective hospital-based study (one hospital), Jan 2021-Jun 2023	Individuals admitted to the tertiary care University Hospital Center of Rabat (Morocco) who exhibited symptoms indicative of respiratory infections and underwent Multiplex Respiratory Panel PCR testing. Hospitalized.	3248	Median: 2 mo	35 (63.4) of those tested positive	NA	NA	PCR	Good
A. Lamrani Hanchi et al. [28], Retrospective hospital-based study (one hospital), Jan 2018-Dec 2019	Children < 14y with severe bronchiolitis, respiratory distress, pneumonia, influenza-like illness in immunocompromised children, and suspicion of pertussis that required hospitalization. Excluded children with noninfectious or chronic respiratory disease. Hospitalized.	534	Mean (median): 17.6 (4)mo • < 6 mo: 292 (54.7) • 6 mo-1 y: 114 (21.3) • 1–2 y: 42 (7.9) • 2–5 y: 40 (7.5) • > 5 y: 46 (8.7)	224 (41.9)	NA	NA	PCR[C]	Good
A. Rabi et al. [29], Letter to the editor reporting on a Prospective hospital-based study (one hospital), Jan 2018-Mar 2019	Children < 14y admitted as probable cases of pertussis (WHO criteria) to the Pediatric pole of the university hospital center in Marrakech. Hospitalized.	81	NA	NA	Infants < 3 mo • 90% unvaccinated • 2 received 1 dose The only 4 mo old received 2 doses. Only a 13-y old girl received all doses	24/24 (100) of confirmed cases	PCR	Good

Table 1 (continued)

Author, study design, period	Population case definition	Sample size	Age group *N* (%)	Females *N* (%)	Vaccination status *N* (%)	Anti-biotic use prior to sampling *N* (%)	Naso-pharyn-geal [A] sample testing using	Quality
K. Katfy (2020) et al. [31], Cross-sectional hospital-based (multiple hospitals), Nov 2015 to Oct 2017	Children < 14 y at Ibn Rochd University Hospital at Casablanca with clinical suspicion of pertussis disease. Hospitalized	128	Mean ± SD: 60 ± 10 d < 2 mo: 111 (87)	NA	Unvaccinated: • < 2 mo: 111 (187)	119 (93.0) Timing NA	PCR[D]	Good
K. Katfy (2017) et al. [30], Prospective hospital-based study (one hospital), Jan 2013 -Jun 2015	Children < 14 y admitted to the Abderrahim Harouchi Pediatric Hospital in Casablanca with clinical suspicion of pertussis (WHO criteria). Hospitalized.	156	Mean ± SD: 60 ± 10 d • < 2 mo: 89 (57.1) • > 2 mo: 67 (42.9)	NA	Unvaccinated: 95 (61) • < 2 mo: 89 (100) .	78/88 (89) of confirmed cases	PCR[E]	Good
Oman								
F. Birru et al. [38], Retrospective hospital-based study (two hospital), Jan 2013 -Dec 2018	Children aged < 13 y who tested positive for B. pertussis by PCR. Excluded patients who presented to the outpatient clinic. Hospitalized.	157	Median: 8 (IQR 5–12) wks • < 2 mo: 83 (52.8) • 2–< 4 mo: 57 (36.3) • 4–<6 mo: 10 (6.4) • ≥ 6 mo: 7 (4.5)	70/150 (46.7)	• Complete vaccination: 8/146 (5.5) • Partial vaccination: 71/146 (49) • Unvaccinated: 67/146 (46)	48 (30.6) Timing NA	PCR	Good
S. Al Awaidy [40], Countrywide surveillance, 1981–2015	Pertussis data on the entire population of Oman collected from various sources, including Annual Health Reports, annual Ministry of Health progress reports, ex. Directorate General of Health Afairs, and Community Health and Diseases Surveillance Newsletter. Hospitalization status NA Suspected case: Cough and ≥ 1 of the following: paroxysms of coughing, inspiratory 'whoop', posttussive vomiting, WBC with absolute lymphocytes ≥ 15,000/mm^3 , and cases that were clinically or laboratory-confirmed. Confirmed case: suspect case with positive isolation of B. pertussis, a significant rise in specific antibody (e.g., IgG or IgA), or with an epidemiological link (e.g., household contact with laboratory-confirmed case within 28 d before or after the onset of illness).	3 992 893 total population of Oman in 2014.	NA	NA	1997: nearly all cases were unvaccinated	NA	Culture or PCR	Good

Table 1 (continued)

Author, study design, period	Population case definition	Sample size	Age group *N* (%)	Females *N* (%)	Vaccination status *N* (%)	Anti-biotic use prior to sampling *N* (%)	Naso-pharyn-geal [A] sample testing using	Quality
A. Al-Maani et al. [39], Retrospective hospital-based study (two centers), Jan 2012-Dec 2013	Children < 13 y admitted with the diagnosis of PLS or pertussis in the 2 tertiary care facilities in Oman (RH and SUH, both in Muscat). Hospitalized This group represents 29.8% (131/439) of the nationally reported cases within the same period	131	• < 2 mo: 49 (37.4) • 2 – 4mo: 50 (38.1) • 4 – 6mo: 14 (10.6) • 6 – 8mo: 6 (4.5) • 8 – 12mo: 6 (4.5)	79 (60.3)	Vaccinated: 54 (41.2) • 1 dose: 30 (22.9) • 2 doses: 11 (8.4) • 3 doses: 13 (9.9) Unvaccinated: 61 (46.5) Unknown: 16 (12.2)	NA	Culture and/or PCR	Good
Pakistan								
S. Omer et al. [44], Community surveillance (4 primary healthcare centers), Feb 2015-Apr 2016	An open cohort, with 1800 (89.1%) infants enrolled at ages up to 10 wks and followed through 18 wks of age, and a closed cohort, with pregnant women enrolled on or after 27 wks' gestation or mothers enrolled who gave birth within the prior 72 h; 221 (10.9%) infants born to these women were followed through 18 wks of age. 2 outcome definitions: 1) Syndromic definition (presenting with any of the following: cough for ≥ 1d, coryza, whoop, apnea, posttussive vomiting, cyanosis, seizure, tachypnea (> 50 bpm for infants > 2 mo or > 60 bpm for infants < 2 mo), severe chest indrawing, movement only when stimulated (or an alternative definition of lethargy), poor feeding (confirmed by poor suck), close exposure to any family member with a prolonged afebrile cough illness, or axillary temperature ≥ 38 °C) with a positive PCR for B. pertussis; and (2) US CDC case definition of probable or confirmed pertussis.	2021	Median (IQR): 20 (9–41) d	964 (47.7)	NA	NA	PCR	Fair

Table 1 (continued)

Author, study design, period	Population case definition	Sample size	Age group *N* (%)	Females *N* (%)	Vaccination status *N* (%)	Anti-biotic use prior to sampling *N* (%)	Naso-pharyn-geal [A] sample testing using	Quality
A. Mughal et al. [43], Prospective hospital-based study (2 hospitals), NA	Vaccinated children with suspected whooping cough (clinical history and case definitions of pertussis recommended by the WHO: cough for > 2 wks with paroxysms, vomiting, and whoop), aged 1–84 mo, visiting the Diagnostic and Research Centre or the Outpatient Department of the District Civil Hospital. Hospitalized and nonhospitalized	700	Range: 1–84 mo	NA	Vaccinated: 700 (100)	NA	Culture followed by PCR[F]	Good
Palestine								
K. Dumaidi et al. [48], Retrospective hospital-based study (multiple hospitals), Sep 2004-Jun 2008	Children with clinically-suspected pertussis (Based on WHO clinical case definition: paroxysms of cough for ≥ 2 wks with respiratory whooping posttussive vomiting, without other apparent causes. However, < 2 wks of paroxysmal cough was adopted to account for milder infections to prevent missing cases) who were admitted to West Bank hospitals. Hospitalized	267	(*N* = 234): • < 2 mo: 137 (58.5) • 2–4 mo: 63 (23.5) • 5–6 mo: 13 (5.6) • 7–12 mo: 7 (3.0) • > 12: 14 (6.0)	116 (43.4)	NA	NA	PCR	Good
Saudi Arabia								
A. Almojali et al. [42], Retrospective hospital-based study (one hospital), Jan 2019-Dec 2020	Children selected through stratified random sampling (based on sex and age groups) from 816 infants ≤ 90 d of age with confirmed viral RTI (≥ 1 viruses on respiratory multiplex PCR from a nasopharyngeal aspirate). Hospitalized	322	• 0–28 d: 90 (28.0) • 29–60 d: 125 (38.8) • 61–90 d: 107 (33.2)	143 (44.4)	NA	NA	PCR[D]	Poor

Table 1 (continued)

Author, study design, period	Population case definition	Sample size	Age group *N* (%)	Females *N* (%)	Vaccination status *N* (%)	Anti-biotic use prior to sampling *N* (%)	Naso-pharyn-geal [A] sample testing using	Quality
J. Al-Tawfiq et al. [41], Retrospective clinic/hospital-based study (company-operated and privately contracted clinics/hospitals), Jan 1996-Dec 2004	Individuals with confirmed B. pertussis (based on positive nasopharyngeal swab cultures or PCRs) retrieved from the epidemiology database, which includes all reportable infectious diseases in Saudi Aramco Medical Services Organization (SAMSO). SAMSO provides medical care for Saudi Aramco employees and their dependents (*N* = 370,000 individuals). Hospitalized and nonhospitalized.	156	• < 6 mo: 81 (51.9) • 6–11 mo: 8 (5.1) • 1–4 y: 13 (8.3) • 5–9 y: 8 (5.1) • 10–19 y: 24 (15.4) • ≥ 20 y: 22 (14.1)	68 (43.6)	Of hospitalized infants • Unvaccinated: 41 (65) • 1 dose: 17 (27) • 2 doses: 3 (4.8) • 3 doses: 2 (3.2) < 6 mo of age • Unvaccinated: 47 (58) • 1 dose: 32 (39.5) • 2 doses: 2 (2.5)	NA	Culture or PCR	Good
Sudan								
B. Abdalla et al. [49], Prospective hospital-based study (one hospital), Jul 1989-Aug 1990	Children (*N* = 37) presenting to the Children's Emergency Hospital in Khartoum with clinical pertussis (WHO diagnostic criteria). Each case was followed at home where other cases (*N* = 5) living in the household or a neighboring house were also identified. Hospitalized	42	• < 1 y: 10 (23.8) • 1–5 y: 10 (23.8) • > 5 y: 22 (52.4)	Male: female ratio: l:1.6	• Unvaccinated: 32 (76.2) • 1 does: 4 (9.5) • 2 doses: 4 (9.5) • 3 doses: 2 (4.8)	32 (76.2)	NA	Fair
Syria								
A. Terkawi et al. [50], Prospective data registry study, Feb-Dec 2017	Population of the HealthySyriaTB program which is a simplified electronic medical record system under the Syrian Expatriate Medical Association (SEMA). The study center is located in the northwest Syrian in Atmeh, in Idlib governorate; close to several camps that house scores of internally displaced individuals. In the study district, there are a total of five medical centers. Diagnosis was made based on clinical presentation and supported by the presence of leukocytosis.	11,819	• 1–27 d: 862 (7.3) • 28–364 d: 3662 (31.0) • 1–4 y: 2383 (20.2) • 5–9 y: 2103 (17.8) • 10–14 y: 988 (8.4) • 15–19 y: 1821 (15.4)	6531 (55.3)	NA	NA	NA	Good

Table 1 (continued)

Author, study design, period	Population case definition	Sample size	Age group *N* (%)	Females *N* (%)	Vaccination status *N* (%)	Anti-biotic use prior to sampling *N* (%)	Naso-pharyn-geal [A] sample testing using	Quality
Tunasia								
I. Ben Fraj et al. [33], Prospective hospital-based study (one hospital), Mar 2007- Mar 2016	All children hospitalized at the Children's Hospital of Tunis for respiratory tract infection and suspicion of pertussis. Hospitalized	1844	Median (IQR): 2 (1–3) Range: few days after birth – 10y • < 2 mo: 1169 (62.9) • 2–6 mo: 550 (29.8) • 6–12 mo: 102 (5.5) • 1–5 y: 25 (1844) • 5–10 y: 8 (0.4)	815 (44.2)	NA	140/306 (46) of confirmed cases	PCR[G]	Good
A. Borgi et al. [35], Retrospective hospital-based study (one hospital), Jan 2013-Oct 2013	Children with critical pertussis confirmed by RT-PCR and requiring mechanical ventilation. Hospitalized	17	Median (range): 50 (24–630) d • < 2 mo: 9 (52.9) • 2–12 mo: 7 (41.2) • ≥ 1 y: 1 (5.9)	9 (52)	Partially vaccinated (1 dose): 5(29) • Survivors: 1(7.6) • Deaths: 4 (100)	17 (100) Timing NA	PCR[H]	Good
A. Zouari (2012) et al. [36], Prospective hospital-based study (cases referred to one hospital), Mar 2007-Mar 2011	Children < 1 y of age with or without suspected pertussis from the Children's Hospital of Tunis (4 wards of general pediatrics and 1 PICU) and other public health clinics that were referred to the Microbiology Laboratory at Children's Hospital of Tunis.	599	Mean: 2.4 mo Range: 1 d to 11 mo • < 2 mo: 5% • 2-<3 mo: 20% • 3-<6 mo: 20% • 6–11 mo: 9%	267 (44.6)	Unvaccinated: 72% Correctly vaccinated: 17% • 1 dose (Pw): 79 (13%) • 2 doses: 42 (7%) • 3 doses: 21 (4%) • Unknown doses: 27 (5%)	219 (37)	PCR[I]	Good
A. Zouari (2011) et al. [34], Prospective hospital-based study (one hospital), Mar 2007-Mar 2008	Children < 1 y of age presenting a clinical picture of pertussis and hospitalized in general pediatric and intensive care units at the Children's Hospital of Tunis. Hospitalized	74	Range: 1 d 11 mo • < 2 mo: 44 (59.5) • 2–3 mo: 14 (18.9) • 3–6 mo: 13 (17.6) • 6–11 mo: 3 (4.1)	33 (44.6)	Unvaccinated: 51 (68.9) • < 2 mo: 44 (100) • 2–3 mo: 4 (28.6) • 3–6 mo: 3 (23.1) 1 does: 13 (17.6) • 2–3 mo: 10 (71.4) • 3–6 mo: 3 (23.1) 2 does: 7 (9.5) • 3–6 mo: 7 (53.8) 3 does: 3 (4.1) • 6–11 mo: 3 (100)	30 (40.5)	PCR	Good
A. Bouziri et al. [37], Retrospective hospital-based study (one hospital), 2006–2008	Infants aged < 3 mo admitted to the PICU for severe acute respiratory failure requiring the use of mechanical ventilation and presenting major hyperleukocytosis, defined by a rate > 50,000/mm. Hospitalized	10	Median: 2.1 mo Range: 0.6–3 mo	6 (60.0)	Unvaccinated: 10 (100.0)	10 (100) Timing NA	PCR[J]	**Good**

Abbreviations: *CAP* Community-acquired pneumonia, *CDC* Center for Disease Control and Prevention, *d* days, *RR* Respiratory rate, *Bpm* breaths per minute, *IQR* Interquartile range, *Mo* Month, *NA* Not available, *No*. Number, *NS* nonsignificant, *PICU* Pediatric Intensive Care Unit, *PLS* Pertussis-like syndrome; *SARI* Severe acute respiratory illness, *WHO* World Health Organization, *Y* years,

A: All used nasopharyngeal samples, unless otherwise specified; B: Used sputum samples collected from the lower respiratory tract by using a mucus trap catheter after sputum induction; C: Tested nasopharyngeal swabs from enrolled children and distal respiratory specimens (protected distal brush or bronchoalveolar lavage) from intubated children hospitalized in the PICU.; D: Nasopharyngeal aspirates were tested; E: Infants (< 12 months) were sampled by nasopharyngeal aspiration. Older children (> 12 months) and adults were sampled by nasopharyngeal swabs; F: Samples were collected through cough plates exposed to a maximum of three coughing bouts; G: 98% of the samples tested were nasopharyngeal aspirates, 2% were tracheal samples and bronchial secretions; H: Nasopharyngeal and/or tracheal secretions were tested; I: Nasopharyngeal aspirates, tracheal sampling, or nasopharyngeal swabs were tested; J: PCR was done on nasopharyngeal washes review process [18]. Regarding funding, fifteen studies did not report any details on funding received. Ten studies explicitly stated they received no financial support, while six studies reported financial backing from university funds, with five based in Iran [18, 20–22, 24, 26] and one in Jordan [47]. Two studies acknowledged support from the pharmaceutical industry [30, 31], and two others were funded by nonprofit foundations [19, 44]. Additional details are available in Additional file 5.

Incidence of Pertussis Infection in healthy infants

Three surveillance studies reported the incidence of pertussis infection in the population of infants in Iran [26], Oman [40], and Pakistan [44]. In Iran, a country-wide surveillance study reported the mean annual rates of culture or PCR-confirmed pertussis cases in infants under 2 months as 293 per 100,000 population during 2008–2011 [26]. This decreased to 103 per 100,000 population in infants aged 2–12 months [26]. In Oman, a country-wide surveillance study found that the incidence of pertussis in infants under 3 months was 4,702 per 100,000 population in 1997 [40]. By 2013, the incidence had decreased to 1,390 per 100,000 population in infants under 2 months [40].

The community surveillance study from Pakistan was the only study to prospectively follow healthy infants with a median age of 20 days until 18 weeks of age [44]. Eight (0.4%) out of 2021 followed cases developed pertussis [44]. This translated to an incidence of 3.96 (95% confidence interval (CI), 1.84–7.50) per 1000 infants, with a median (IQR) age at diagnosis of 18 (14–26.5) days [44].

Population-specific proportion of Pertussis infection

Proportion of pertussis infection in infants with respiratory tract infections

Four studies reported on the proportion of pertussis infection in infants with respiratory tract infections not limited to PLS [28, 37, 42, 51]. The first, a cross-sectional hospital-based study conducted in Egypt, examined previously healthy children under 5 years of age hospitalized with CAP and found that 7.7% of infants under 4 months had confirmed pertussis [51]. The second study, conducted in Saudi Arabia, focused on infants under 90 days old who were admitted with confirmed viral respiratory tract infections [42]. In this cohort, 2.5% of the cases were confirmed as pertussis [42]. The third study, from Tunisia, found that all infants under 3 months of age admitted to the pediatric Intensive care unit (PICU) for severe acute respiratory failure had confirmed pertussis, with 100% of the 10 cases testing positive [37]. The fourth study, conducted in Morocco, reported that the proportion of B. *Pertussis* was 6.7% in children under 12 months and 8.9% in children under 6 months with severe bronchiolitis, respiratory distress, pneumonia, Influenza-like illness in immunocompromised children, and PLS [28].

Proportion of Pertussis Infection in infants with PLS

Nine studies, including three from Tunisia [33, 34, 36], two from Iran [23, 24], and one each from Palestine [48], Sudan [49], Pakistan [43], and Iraq [45], reported on the incidence rate of B. Pertussis in infants aged 1 year and under presenting with PLS. In studies using PCR for diagnosis, the proportion of pertussis cases varied, ranging from 16.4% in hospitalized children in Tunisia [33] to 50.4% in Palestine [48]. A study from Iraq also reported a proportion of 50.4% in children under one year of age, despite using only culture for diagnosis [45] (Table 2).

A total of eight studies, four from Iran [19, 22, 24, 25], and one from Tunisia [33], Pakistan [43], and Palestine [48] reported the proportion of B. *Pertussis* in infants aged 6 months or younger with PLS. The rates varied in studies using PCR only for diagnosis, ranging from 16.6% in hospitalized children in Tunisia [33] to 51.6% in infants in a multi-hospital retrospective study from Palestine [48] (Table 2).

Regarding infants aged 2 months or younger with PLS, two countrywide surveillance studies from Iran reported the proportion of pertussis: 2.0% (culture-confirmed) [17], and 10.5% (confirmed by either culture or PCR) [23]. Six additional hospital-based studies from Morocco [30, 31], Tunisia [33, 34], Palestine [48], and Iran [27] reported proportions ranging between 6.7% in Iran (culture-confirmed) and 73.0% in Morocco (PCR-confirmed) [30] (Table 2).

Moreover, a cross-sectional hospital-based study in Iran reported that 15 out of 45 children under 5 years of age (mean age: 3.2 ± 2.5 months) with PLS had confirmed pertussis [18]. The mean age of those with confirmed pertussis was 2.8 months (± NA) [18]. Additionally, a hospital-based study in Pakistan among vaccinated children aged 1 month to 7 years reported 22 culture-confirmed pertussis cases out of 700 with suspected whooping cough [43]. The incidence rates were 4.5%, 4.5%, and 13.6% in children aged 6 months, 10 months, and 12 months, respectively [43].

Age distribution

Country/Province-wide surveillance studies

Seven surveillance studies reported on the age distribution of pertussis cases, five in Iran [17, 20, 21, 23, 26], two reported on the same population [20, 21], one in Oman [40], and another in Iraq [46]. In Iran, between 2009 and 2010, 25.0% of confirmed pertussis cases were in infants under 2 months [17]. From 2011 to 2013, 41.4% of confirmed cases were in infants under 2 months and 74.9% were under 1 year [23]. Between 2008 and 2011, 13.7% of clinically reported cases were under 2 months and 37.7% were under 1 year [26]. Additionally, out of all suspected cases of pertussis registered in the Department

Table 2 Proportion of B. *Pertussis* infection in infants with PLS < 1 year, 6 months, and 2 months

Author, year: study type country, period	Population studied	Confirmatory test	*N* (%) of cases per age category		
			< 12 mo	< 6 mo	< 2 mo
Countrywide surveillance					
G. Ghorbani et al., 2016 [23] Iran: 2011–2013	Individuals with PLS (hospitalization status NA)	Culture or PCR	179/2274 (7.9)	-	99/939 (10.5)
F. Shahcheraghi et al., 2012 [17] Iran: 2009–2010	Individuals with PLS (hospitalization status NA)	Culture	-	-	3/152 (2.0)
M. Hajia et al., 2012 [25] Iran: Oct 2008-Mar 2011	Children with PLS (hospitalization status NA)	Culture or PCR	-	11/138 (8.0)	-
Hospital-based cohorts					
A. Lamrani Hanchi et al., 2021 [28]: Retrospective (1 hospital) Morocco: Jan 2018-Dec 2019	Children with severe bronchiolitis, respiratory distress, pneumonia, ILI in immunocompromised children, and PLS (hospitalized)	PCR	27/406 (6.7)	26/292 (8.9)	-
K. Katfy et al., 2020 [31]: Cross-sectional (multi-hospital) Morocco: Nov 2015-Oct 2017	Children with PLS (hospitalized)	PCR	-	-	64/111 (57.7)
I. Ben Fraj et al., 2019 [33]: Prospective (1 hospital) Tunisia: Mar 2007-Mar 2016	Children with PLS (hospitalized)	PCR	299/1821 (16.4)	286/1719 (16.6)	191/1169 (16.3)
S. Mahmoudi et al., 2018 [22]: Cross-sectional (1 hospital) Iran: Aug 2014-Aug 2015	Children with PLS (hospitalized)	PCR	-	16/66 (24.2)	-
K. Dumaidi et al., 2018 [48]: Retrospective (multi-hospital) Palestine: Sep 2004-Jun 2008	Children with PLS (hospitalized)	PCR	113/220 (51.4)	110/213 (51.6)	68/137 (49.6)
K. Katfy et al., 2017 [30]: Prospective (1 hospital) Morocco: Jan 2013- Jun 2015	Children with PLS (hospitalized)	PCR	-	-	65/89 (73.0)
A. Zouari et al., 2012 [36]: Prospective (1 hospital) Tunisia: Mar 2007-Mar 2011	Children with or without PLS (hospitalized and not hospitalized)	PCR	108/ 599 (18.0)	-	-
A. Zouari et al., 2011 [34]: Prospective (1 hospital) Tunisia: Mar 2007-Mar 2008	Children with PLS (hospitalized)	PCR	30/74 (40.5)	-	17/44 (38.6)
G. Noel et al., 2021 [19]: Prospective (2 hospitals) Iran: Nov 2016-May 2019	Children with PLS (most hospitalized)	Culture or PCR	-	40/199 (20.1)	-
M. Bahri et al., 2013 [27]: Cross-sectional (1 hospital) Iran: Apr 2008-Jul 2012	Children with PLS (hospitalized)	Culture	-	-	4/60 (6.7)
J. Shojaei et al., 2014 [24]: Retrospective (1 hospital) Iran: Mar 2008-Apr 2012	Children with PLS (hospitalized)	Culture or PCR	19/118 (16.1)	12/83 (14.5)	-
A. Mughal et al., 2012 [43]: Prospective (2 hospitals) Pakistan: NA	Vaccinated children with PLS (hospitalized and not hospitalized)	Culture followed by PCR	NA/NA (13.7)	NA/NA (4.5)	-
K. Al-Bargish, 1999 [45]: Cross-sectional (1 hospital) Iraq: Jun 1996-Dec 1996	Individuals with PLS (most hospitalized)	Culture	18/35 (51.4)	-	-
B. Abdalla et al., 1998 [49]: Prospective (1 hospital) Sudan: Jul 1989-Aug 1990	Children with PLS (hospitalized)	NA	1/10 (10.0)	-	-

Abbreviations: *ILI* Influenza-like illness, *PCR* Polymerase chain reaction, *PLS* Pertussis-like syndrome, *Mo* months, *NA* Not available of Vaccine-preventable Diseases in the Iranian Ministry of Health, around 63% were under 1 year of age between 2012 and 2018 [20, 21]. In Oman, a surveillance study reported that around 45.5% of pertussis cases were in infants under 2 months, and 79.6% were under 1 year between 2011 and 2015 [40]. In Anbar Province, Iraq, a province-wide surveillance study reported that 26.0% of confirmed pertussis cases were 1 year or younger between 2009 and 2019 [46]. However, this study relied on serodiagnosis of pertussis, not culture or PCR [46] (Table 3).

Age distribution across all-age group cohort studies

Three cohort studies focused on the percentage of confirmed pertussis cases in infants within the entire patient population [32, 41, 45]. In Iraq in 1996 and Saudi Arabia between 1996 and 2004, cases in infants under 1 year of age accounted for 42.3% and 57.1% of confirmed cases, respectively [41, 45]. In Morocco between 2021 and 2023, cases in infants under 3 months constituted 78.2% of confirmed cases among individuals hospitalized with respiratory infections [32] (Table 3).

In Syria, a study from the HealthySyriaTB program reported 9 cases of pertussis with a median age of 0.8 years (min-max: 0.3–8 years), with infants being the most affected group. However, laboratory tests did not confirm the diagnosis [50].

Age distribution in cohort studies of children aged < 7–10 and 15 years

Six studies, three from Morocco [29–31] and one from Oman [39], Iran [27], and Sudan [49], reported on the age distribution of pertussis cases among hospitalized children under 15 years with PLS. Confirmed cases in infants under 2 months of age ranged between 33.3% in Oman [39] to 73.9% in Morocco [30]. Additionally, around 95.8–100% of the cases were under 5 months in a study from Morocco [29] and Oman [39], respectively. The study from Sudan only reported clinically diagnosed pertussis cases, of which around 19.0% were under 1 year of age (Table 3).

Similarly, two studies from Tunisia [33] and Egypt [51] reported on the age distribution of pertussis cases among hospitalized children under 7–10 years old with PLS or CAP. Approximately 62.4% of confirmed cases were in infants under 2 months in Tunisia [33], and 100% were in infants under 6 months in Egypt [51].

Age distribution in cohort studies of children aged < 2 years

Four studies, from Iran [22], Jordan [47], Morocco [28], and Tunisia [35], reported on the age distribution of pertussis cases among children under 2 years. In Iran and Morocco, 88.9% [13] and 83.9% [28] of confirmed cases were under 6 months of age, respectively. In Jordan, 100% of cases were in infants aged 2 months or younger among children hospitalized with fever and/or respiratory symptoms [47]. In Tunisia, almost all cases of critical pertussis were under 1 year of age, with around 52.9% being younger than 2 months [35] (Table 3).

Age distribution in cohort studies of children aged < 6 months and < 1 years

Three studies reported on the age distribution of pertussis in children < 1 year. In Iran, around 63.2% of cases were in infants < 6 months among children hospitalized with PLS [24]. In Tunisia, infants < 2 months constituted around 48.3–56.7% of confirmed cases of pertussis [34, 36]. Additionally, two studies reported on the age distribution in children < 6 months. In Oman, 52.9% of cases were in infants ≤ 2 months, 89.2% were ≤ 4 months [38], and in Iran, around 77.5% of the cases were under 3 months [19] (Table 3).

Distribution by vaccination status

Various studies highlight the occurrence of pertussis in both vaccinated and unvaccinated individuals, though the distribution varies by age group and vaccination status. In Iran, studies found that only 24.4–46.0% of confirmed pertussis cases were in unvaccinated individuals [17, 23, 26]. In Iraq, a study conducted in 1999 revealed that 81.0% of B. Pertussis cases were among vaccinated individuals [45] (Table 4).

When examining the age distribution and vaccination status, studies reported that a large proportion (50.0–83.3%) of pertussis cases in the under 15 years age group were unvaccinated [29–31, 39]. Similar trends were observed in studies on children under 2 years of age and children under 1 year of age, where the majority of cases were unvaccinated, and a significant portion were only partially vaccinated (i.e., received one or two doses but had not completed the full vaccination schedule) [22, 24, 34–36, 47]. Studies on infants under 6 months revealed that around 50% of the cases were in unvaccinated infants, while the other half were only partially vaccinated [19, 38] (Table 4).

Hospitalization

Table 5 presents data on the impact of pertussis, particularly among children. Most studies, including hospitalized and non-hospitalized patients, reported high hospitalization rates, especially among infants and young children [19, 26, 36, 40, 41, 45]. Studies have found that infants under 6 months old are particularly vulnerable, with nearly all cases in this age group resulting in hospitalization [19, 36, 41].

In addition to the two studies on cases admitted to the PICU [35, 37], multiple studies have also reported the need

Table 3 Age distribution of confirmed B. *Pertussis* cases

Author, year: type country, period	Population studied mean ± SD age, months	*N* of cases	Age distribution of confirmed B. *Pertussis* cases *N* per age group (% out of total confirmed cases)				
			< 2 mo	< 3 mo	< 6 mo	< 1 y	Other
Country/Province -Wide surveillance							
Y. Alimohamadi et al., 2020 (20, 21): Country-wide Iran: Feb 2012-23 Mar 2018	Individuals with PLS (hospitalization status NA)	7775	-	-	-	4872 (62.7)	-
G. Ghorbani et al., 2016 [23]: Country-wide Iran: 2011–2013	Individuals with PLS (hospitalization status NA)	239[A]	99 (41.4)	-	-	179 (74.9)	• 1–5 y: 21 (8.8) • 6–10 y: 16 (6.7) • > 10 y: 23 (9.6)
F. Shahcheraghi et al., 2012 [17]: Country-wide Iran: 2009–2010	Individuals with PLS (hospitalization status NA)	12[B]	3 (25.0)	-	-	-	• 2 mo-2 y: 6 (50.0) • 2–10 y: 2 (16.7) • > 10 y: 1 (8.3)
M. Saffar et al., 2014 [26]: Country-wide Iran: 2008–2011	Individuals with PLS or pertussis (hospitalization status NA)	518 (only 45 confirmed)[A]	71 (13.7)	-	-	196 (37.7)	-
S. Al Awaidy, 2018 [40]: Country-wide Oman: 1981–2015	Individuals with PLS or pertussis (hospitalization status NA)	• 1997: 694 • 2013: 300 • 2011-15: 785[A]	• 2013: 168 (56.0) • 2011-15: 357(45.4)	• 1997: 490 (70.6) • 2011-15: 486 (61.9)	2011-15: 566 (72.1)	2011-15: 625 (79.6)	-
E. Mohammed Abdullah et al. [46], **2021**: Province-wide Iraq: 2009–2019	Individuals with confirmed pertussis (hospitalized and not hospitalized)	607[C]	-	-	-	158 (26.0)	-
Cohort studies							
Individuals of all ages							
K. Al-Bargish, 1999 [45]: Cross-sectional (1 hospital) Iraq: Jun-Dec 1996	Individuals with PLS (most hospitalized)	42[B]	-	-	-	18 (42.3)	-
J. Al-Tawfiq et al., 2007 [41]: Retrospective (company-operated/privately contracted clinics/hospitals) Saudi Arabia: Jan 1996-Dec 2004	Individuals with confirmed pertussis (hospitalized and not hospitalized)	156[A]	-	-	81 (51.9)	89 (57.1)	• 1–4 y: 13 (8.3) • 5–9 y: 8 (5.1) • 10–19 y: 24 (15.4) • ≥ 20 y: 22 (14.1)
R. Bennai et al., 2024 [32]: Retrospective (1 hospital) Morrocco: Jan 2021-Jun 2023	Individuals with respiratory infections (hospitalized)	55	-	43 (78.2)	-	-	• 3–5 mo : 2 (3.6) • 5–19 mo: 2 (3.6) • 19–61 mo: 3 (5.5) • 61–180 mo: 0 • > 180 mo: 5 (9.1)

Table 3 (continued)

Author, year: type country, period	Population studied mean ± SD age, months	*N* of cases	Age distribution of confirmed B. *Pertussis* cases *N* per age group (% out of total confirmed cases)				
			< 2 mo	< 3 mo	< 6 mo	< 1 y	Other
Children < 15 years							
K. Katfy et al., 2020 [31]: Cross-sectional (multi-hospital) Morocco: Nov 2015-Oct 2017	Children with PLS (hospitalized) < 14 y	87	64 (73.5)	73 (83.9)	-	-	3–14 mo: 12 (13.8)
A. Rabi et al., 2019 [29]: Letter to the editor of a Prospective study (1 hospital) Morocco: Jan 2018-Mar 2019	Children with PLS (hospitalized) < 14 y	24	14 (58.3)	22 (91.7)	-	-	• 3–5 mo: 1 (4.2) • 5 mo–12 y: 0 (0) • > 12–<14y: 1 (4.2)
K. Katfy et al., 2017 [30]: Prospective (1 hospital) Morocco: Jan 2013-Jun 2015	Children with PLS (hospitalized) < 14 y	88	65 (73.9)	-	-	-	2mo-14y: 23 (26.1)
A. Al Maani et al., 2017 [39]: Retrospective (2 Hospitals) Oman: Jan 2012-Dec 2013	Children with PLS or pertussis (hospitalized) < 13 y	12[A]	4 (33.3)	-	12 (100)	12 (100)	2–4 mo: 7 (58.3)
M. Bahri et al., 2013 [27]: Cross-sectional (1 hospital) Iran: Apr 2008-Jul 2012	Children with PLS (hospitalized) < 14 y	7[B]	4 (57.1)	-	-	-	2mo-12y: 3 (42.9)
B. Abdalla et al., 1998 [49]: Prospective (1 hospital) Sudan: Jul 1989-Aug 1990	Children with PLS (hospitalized) < 15 y	42[D]	-	-	-	8 (19.0)	• 1–5 y: 12 (28.6) • > 5 y: 22 (52.4)
Children < 7–10 years							
I. Ben Fraj et al., 2019 [33]: Prospective (1 hospital) Tunisia: Mar 2007-Mar 2016	Children with PLS (hospitalized) Median (IQR): 2 (1–3) Range: few days after birth – 10y	306	191 (62.4)	-	286 (93.5)	299 (97.7)	• 1–5 y: 5 (1.6) • 5–10 y: 2 (0.7)
N.R. El Basha et al., 2019 [51]: Cross-sectional (2 hospitals) Egypt: Aug 2015-Sept 2017	Children with CAP (hospitalized) 13.8 ± 15.5 mo Range: 2–84 mo	8	-	-	-	-	≤ 4 mo: 8 (100)

Table 3 (continued)

Author, year: type country, period	Population studied mean ± SD age, months	*N* of cases	Age distribution of confirmed B. *Pertussis* cases *N* per age group (% out of total confirmed cases)				
			< 2 mo	< 3 mo	< 6 mo	< 1 y	Other
Children < 2 years							
S. Mahmoudi et al., 2018 [22]: Cross-sectional (1 hospital) Iran: Aug 2014-Aug 2015	Children with PLS (hospitalized) < 2 y 5.5 ± NA mo	18	-	-	16 (88.9)	-	-
M. Jayyosi et al., 2015 [47]: Prospective (1 hospital) Jordan: 2010–2012	Children with fever and/or respiratory symptoms (hospitalized) < 2 y	2	2 (100)	-	-	-	-
A. Lamrani Hanchi et al., 2021 [28]: Retrospective (1 hospital) Morocco: Jan 2018-Dec 2019	Children with severe bronchiolitis, respiratory distress, pneumonia, ILI in immunocompromised children, and PLS (hospitalized) Mean (median): 17.6 (4) mo	31	-	-	26 (83.8)	27 (87.1)	> 1 y: 4 (12.9)
A. Borgi, 2014 [35]: Retrospective (1 hospital) Tunisia: Jan-Oct 2013	Children with pertussis requiring MV (hospitalized) Median (range): 50 (24–630) d	17	9 (52.9)	-	-	16 (94.1)	≥ 1 y: 1
Children < 1 year							
J. Shojaei et al., 2014 [24]: Retrospective (1 hospital) Iran: Mar 2008-Apr 2012	Children with PLS (hospitalized) < 1 y	19[A]	-	-	12 (63.2)	19 (100)	-
A. Zouari et al., 2011 [34]: Prospective (1 hospital) Tunisia: Mar 2007-Mar 2008	Children with PLS (hospitalized) Range: 1d-11mo	30	17 (56.7)	-	-	-	2–11 mo: 13 (43.3)
A. Zouari et al., 2012 [36]: Prospective (1 hospital) Tunisia: Mar 2007-Mar 2011	Children with or without PLS (hospitalized and not hospitalized) Range: 1d-11mo	120	58 (48.3)	-	114 (95.0)	-	-
Children < 6 months							
G. Noel et al., 2021 [19]: Prospective (2 hospitals) Iran: Nov 2016-May 2019	Children with PLS (most hospitalized) Median (IQR): 2.0 (1.3–2.8) mo Range: 8 d-6 mo	40[A]	-	31 (77.5)	40 (100)	-	-

Table 3 (continued)

Author, year: type country, period	Population studied mean ± SD age, months	*N* of cases	Age distribution of confirmed B. *Pertussis* cases *N* per age group (% out of total confirmed cases)				
			< 2 mo	< 3 mo	< 6 mo	< 1 y	Other
F. Birru et al., 2021 [38]: Retrospective (2 hospitals) Oman: Jan 2013-Dec 2018	Children with confirmed pertussis (hospitalized) Median: 8 (IQR 5–12) wks	157	83 (52.9)	-	-	-	2–4 mo: 57 (36.3)
Unspecified Age range							
K. Dumaidi et al., 2018 [48]: Retrospective (multi-hospital) Palestine: Sep 2004 and Jun 2008	Children with PLS (hospitalized)	130	68 (52.3)	-	110 (84.6)	113 (86.9)	• > 12 mo: 7 • Unknwon: 10

Abbreviations: *CAP* Community-acquired pneumonia, *d* days, *ILI* Influenza-like illness, *IQR* Interquartile range, *Mo* Months, *MV* Mechanical Ventilation, *NA* Not available, *No*. Number, *PLS* Pertussis-like syndrome, *Wks* weeks, *y* years

A: Confirmed by culture or PCR; B: Confirmed by culture; C: Sero-diagnosis by recognition of "Pertussis-specific IgM" in serum sample; D: Clinically diagnosed and not confirmed by Laboratory

for intensive care among hospitalized individuals with pertussis, with rates ranging from 0 to 59.2% [29, 36, 38, 39, 51]. The duration of hospital stays often extends several days (most reporting around five days [18, 38, 41, 47]), and longer stays are linked with severe cases and younger patients, particularly those requiring intensive care [38].

Serious medical complications and death

Thirteen studies provided data on the mortality rate among pertussis cases. Five studies reported no deaths [24, 26, 39–41], while eight reported mortality rates ranging from 0.6 to 90.0% [19, 29, 35–38, 44, 49]. The studies conducted on infants admitted to the PICU showed particularly high mortality rates [35, 37].

Serious complications were primarily observed in studies involving children under the age of 2 years. This included seizures occurring in 1.9–40.0% of cases, as reported by six studies [24, 32, 35–38], and the need for ventilatory support and mechanical ventilation in 5.5–100.0% of the cases, as reported in five studies [32, 35–38]. In some cases, advanced respiratory support, such as high-frequency oscillation ventilation, was required. Other reported complications included pulmonary hypertension, use of inotropes, and exchange transfusion among others (Table 5).

Maternal pertussis vaccination

The cross-sectional study from Saudi Arabia found that only 3.7% of the women reported taking the pertussis vaccine during previous pregnancies, and 7.0% were recommended to take the vaccine by their healthcare providers. Furthermore, 44.9% of the women agreed to receive the vaccine during pregnancy if it was available for free. The regression analysis showed that age ($P = 0.026$; 95% CI: 0.088–1.363) and educational level ($P < 0.001$; 95% CI: 0.574–1.652) are the only predictors for the total awareness score about pertussis disease and acceptance of its vaccination during pregnancy [52].

Discussion

This systematic review of observational studies highlights the significant burden of pertussis among infants in the EMR, particularly those under six months of age. The high hospitalization rates observed in this age group indicate the severe nature of the disease. These findings align with global patterns, where infants under two months of age are the most vulnerable due to their incomplete vaccination status and reliance on maternal antibodies for protection [5, 9, 53–55]. The consistent identification of infants under six months as the most affected age group across studies highlights the reliability of this finding and its critical importance for public health interventions.

To explore the potential causes of heterogeneity among the study results, we grouped the studies by country to assess the influence of geographic location on pertussis incidence and severity in infants. Substantial variability in incidence rates across EMR countries was evident, emphasizing the complex interplay of factors influencing pertussis epidemiology [56, 57]. Differences in healthcare infrastructure, diagnostic practices,

Table 4 Vaccination status of confirmed B. *Pertussis* cases

Author, year: type country, period	Population studied mean ± SD age, months	*N* pertussis cases with a vaccine status	Vaccination distribution of confirmed B. *Pertussis* cases *N* per group (% out of total confirmed cases)		
			Vaccinated	Unvaccinated	Not fully vaccinated
Countrywide surveillance					
S. Al Awaidy, 2018 [40] Oman: 1981–2015	Individuals with PLS or pertussis (hospitalization status NA)	1997: 694[A]	-	1997: nearly all unvaccinated	-
G. Ghorbani et al., 2016 [23] Iran: 2011–2013	Individuals with PLS (hospitalization status NA)	239	45 (18.8)	110 (46.0)	84 (35.1)
F. Shahcheraghi et al., 2012 [17] Iran: 2009–2010	Individuals with PLS (hospitalization status NA)	12[B]	8 (66.7)	4(33.3)	-
M. Saffar et al., 2014 [26] Iran: 2008–2011	Individuals with PLS or pertussis (hospitalization status NA)	45[A]	-	11 (24.4)	
M. Hajia et al., 2012 [25] Iran Oct 2008-Mar 2011	Children with PLS (hospitalized and not hospitalized)	11[A]	-	11(100.0)	-
Hospital-based cohorts					
Individuals of all ages					
K. Al-Bargish, 1999 [45]: Cross-sectional (1 hospital) Iraq: Jun-Dec 1996	Individuals with PLS (most hospitalized)	42[B]	34 (81.0)	-	-
J. Al-Tawfiq et al., 2007 [41]: Retrospective (company-operated/privately contracted clinics/hospitals) Saudi Arabia: Jan 1996-Dec 2004	Individuals with confirmed pertussis (hospitalized and not hospitalized)	134[A]	47 (35.1)	48 (35.8)	39 (29.1)
Children < 15 years					
K. Katfy et al., 2020 [31]: Cross-sectional (multi-hospital) Morocco: Nov 2015-Oct 2017	Children with PLS (hospitalized) < 14 y	87	-	64 (73.5)	12 (13.8)
A. Rabi et al., 2019 [29]: Letter to editor of a Prospective study (1 hospital) Morocco: Jan 2018-Mar 2019	Children with PLS (hospitalized) < 14 y	24	1 (4.2)	20 (83.3)	3 (12.5)
K. Katfy et al., 2017 [30]: Prospective (1 hospital) Morocco: Jan 2013-Jun 2015	Children with PLS (hospitalized) < 14 y	88	-	65 (73.9)	-
A. Al Maani et al., 2017 [39]: Retrospective (2 Hospitals) Oman: Jan 2012-Dec 2013	Children with PLS or pertussis (hospitalized) < 13 y	10[C]	0	5 (50.0)	5 (50.0)
M. Bahri et al., 2013 [27]: Cross-sectional (1 hospital) Iran: Apr 2008-Jul 2012	Children with PLS (hospitalized) < 14 y	7[B]	-	4 (57.1)	-
Children < 7–10 years					
A. Mughal et al., 2012 [43]: Prospective (1 hospitals) Pakistan: NA	Vaccinated children with PLS (hospitalized and not hospitalized) Range: 1–84 mo	22[D]	22 (100.0)	-	-
N.R. El Basha et al., 2019 [51]: Cross-sectional (2 hospitals) Egypt: Aug 2015-Sept 2017	Children with CAP (hospitalized) 13.8 ± 15.5mo, Range: 2-84mo	8	-	-	8 (100.0)
Children < 2 years					
S. Mahmoudi et al., 2018 [22]: Cross-sectional (1 hospital) Iran: Aug 2014-Aug 2015	Children with PLS (hospitalized) < 2 y, 5.5 ± NA mo	18	-	-	16 (88.9)
M. Jayyosi et al., 2015 [47]: Prospective (1 hospital) Jordan: 2010–2012	Children with fever and/or respiratory symptoms (hospitalized) < 2 y	2	-	2 (100)	-

Table 4 (continued)

Author, year: type country, period	Population studied mean ± SD age, months	*N* pertussis cases with a vaccine status	Vaccination distribution of confirmed B. *Pertussis* cases *N* per group (% out of total confirmed cases)		
			Vaccinated	Unvaccinated	Not fully vaccinated
A. Borgi et al., 2014 [35]: Retrospective (1 hospital) Tunisia: Jan-Oct 2013	Children with pertussis requiring MV (hospitalized) Median (range): 50 (24–630) d	17	-	12 (70.6)	5 (29.4)
Children < 1 year					
J. Shojaei et al., 2014 [24]: Retrospective (1 hospital) Iran: Mar 2008-Apr 2012	Children with PLS (hospitalized) < 1 y	19[A]	4 (21.1)	15 (78.9)	-
A. Zouari et al., 2011 [34]: Prospective (1 hospital) Tunisia: Mar 2007-Mar 2008	Children with PLS (hospitalized) Range: 1d-11mo	30	6 (20.0)	23 (76.7)	1 (33.3)
A. Zouari et al., 2012 [36]: Prospective (1 hospital) Tunisia: Mar 2007 and Mar 2011	Children with or without PLS (hospitalized and not hospitalized) Range: 1d-11mo	115	13 (11.3)	91 (79.1)	11 (9.6)
Children < 6 months					
G. Noel et al., 2021 [19]: Prospective (2 hospitals) Iran: Nov 2016-May 2019	Children with PLS (most hospitalized) Median (IQR): 2.0 (1.3–2.8) mo Range: 8 d-6 mo	40[A]	1 (2.5)	20 (50.0)	19 (47.5)
F. Birru et al., 2021 [38]: Retrospective (2 hospitals) Oman: Jan 2013-Dec 2018	Children with confirmed pertussis (hospitalized) Median: 8 (IQR 5–12) wks	146	8 (5.5)	67 (45.9)	71 (48.6)
Children < 3 months					
A. Bouziri et al., 2010 [37]: Retrospective (1 hospital) Tunisia: 2006–2008	Infants < 3 mo admitted to the PICU for severe acute respiratory failure.	10	-	10 (100.0)	-

Abbreviations: *CAP* Community-acquired pneumonia, *d* days, *IQR* Interquartile range, *Mo* Months, *MV* Mechanical Ventilation, *NA* Not available, *No*. Number, *PICU* Pediatric Intensive Care Unit, *PLS* Pertussis-like syndrome, *Wks* weeks, *Y* years

A: Confirmed by culture or PCR. B: Confirmed by culture. C: Confirmed by culture and/or PCR. D: Confirmed by culture followed by PCR

and reporting mechanisms contribute to this variability [56]. Similar patterns of variability are observed globally, with countries employing different surveillance systems and diagnostic criteria [5]. For instance, countries with robust surveillance and reporting systems, such as those in Western Europe, often report higher incidence rates due to more comprehensive case detection [4, 5]. In the EMR, countries such as Iran and Morocco reported higher incidence rates, likely reflecting better case detection and reporting mechanisms. The EMR countries can benefit from adopting standardized diagnostic and reporting practices, which would facilitate better comparison and more accurate assessment of the disease burden. Tailored public health strategies that consider each country's unique epidemiological patterns and healthcare contexts are essential.

The studies included in this systematic review covered a range of EMR countries, but not all were represented. The majority of the studies came from Iran, Morocco, Tunisia, and Oman. There were fewer studies from Saudi Arabia, Pakistan, Iraq, Jordan, Palestine, Sudan, Syria, and Egypt, and no studies from other countries, especially those with significant healthcare challenges. This uneven representation emphasizes the need for more comprehensive data collection across the region to better understand and address the burden of pertussis. Countries that are underrepresented in the current literature should be prioritized in future research efforts to ensure that accurate and complete data inform public health strategies.

We also organized the incidence data into specific age groups to identify age-related patterns. The highest burden of pertussis was consistently observed in infants under two months of age, with decreasing incidence in older age groups. This age group also experienced the highest rates of severe complications, including seizures and the need for ventilatory support. Seizures and the need for ventilatory support were frequently reported, underscoring the critical nature of pertussis

Table 5 Rate of hospitalization, medical complications, and death among pertussis cases

Author, year: type country, Period	Population studied mean ± SD age, months	*N* of cases	Hospitali-zation *N* (%)	Death *N* (%)	Seizure (*N*%)	Ventilatory support *N* (%)	Other *N* (%)
Countrywide surveillance							
M. Saffar et al., 2014 [26] Iran: 2008–2011	Individuals with PLS or pertussis (hospitalization status NA)	518 (45 confirmed)[A]	243 (46.9)	0	-	-	-
S. Al Awaidy, 2018 [40] Oman: 1981–2015	Individuals with PLS or pertussis (hospitalization status NA)	2011-15: 785[A]	Almost all hospitalized	0	-	-	-
Hospital-based cohorts							
Individuals of all ages							
K. Al-Bargish, 1999 [45]: Cross-sectional (1 hospital) Iraq: Jun-Dec 1996	Individuals with PLS (most hospitalized)	42[B]	10/18 (55.6) < 1 y were hospitalized	-	-	-	-
J. Al-Tawfiq et al., 2007 [41]: Retrospective (company-operated/privately contracted clinics/hospitals) Saudi Arabia: Jan 1996-Dec 2004	Individuals with confirmed pertussis (hospitalized and not hospitalized)	156[A]	65 (41.7) Median (range): 5 (2–21) d 63 (96.6) < 6mo	0	-	-	-
R. Bennai et al., 2024 [32]: Retrospective (1 hospital) Morrocco: Jan 2021-Jun 2023	Individuals with respiratory infections (hospitalized)	55	55 (100.0)	-	2 (3.6)	3 (5.5)	-
Children < 15 years							
A. Al Maani et al., 2017 [39]: Retrospective (2 Hospitals) Oman: Jan 2012-Dec 2013	Children with PLS or pertussis (hospitalized) < 13 y	12[A]	12 (100.0) PICU: 1 (8.3) HDU: 5 (41.7)	0	-	-	-
A. Rabi et al., 2019 [29]: Letter to editor of a Prospective study (1 hospital) Morocco: Jan 2018-Mar 2019	Children with PLS (hospitalized) < 14 y	24	24 (100.0) EU: 8 (33.3) PICU: 3 (12.5)	1 (4.2)	-	-	-
B. Abdalla et al., 1998 [49]: Prospective (1 hospital) Sudan: Jul 1989 to Aug 1990	Children with PLS (hospitalized) < 15 y	42[D]	42 (100.0)	4 (9.5) (1 infant)	-	-	-
Children < 7–10 years							
N.R. El Basha et al., 2019 [51]: Cross-sectional (2 hospitals) Egypt: Aug 2015-Sept 2017	Children with CAP (hospitalized) 13.8 ± 15.5 (Range: 2–84)mo	8	8 (100.0) PICU:0	-	-	-	-
Children < 5 years							
A. Shamsizadeh et al.,2023 [18]: Cross-sectional Iran: Jul 2018-Jul 2019	Children with PLS < 5y (hospitalized)	15	15 (100.0) Mean (range): 4.8 (3–7) d	-	-	-	-

Table 5 (continued)

Author, year: type country, Period	Population studied mean ± SD age, months	*N* of cases	Hospitali-zation *N* (%)	Death *N* (%)	Seizure (*N*%)	Ventilatory support *N* (%)	Other *N* (%)
Children < 2 years							
M. Jayyosi et al., 2015 [47]: Prospective (1 hospital) Jordan: 2010–2012	Children with fever and/or respiratory symptoms (hospitalized) < 2 y	2	2 (100.0) Mean (range): 5 (0–26) d	-	-	-	-
A. Borgi et al.,2014 [35]: Retrospective (1 hospital) Tunisia: Jan-Oct 2013	Children with pertussis requiring MV (hospitalized) Median (range): 50 (24–630) d	17	17 (100.0) PICU: 17 (100.0)	4 (23.6)	1(5.9)	• MV: 17 (100.0) • HFV: 1 (5.9)	• Inotropes: 4 (23.5) • Nitric oxide: 2 (11.7) • Exchange transfusion: 5(29.4)
Children < 1 year							
J. Shojaei et al.,2014 [24]: Retrospective (1 hospital) Iran: Mar 2008-Apr 2012	Children with PLS (hospitalized) < 1 y	19[A]	19 (100.0)	0	1 (5.3)	-	-
A. Zouari et al., 2012 [36]: Prospective (1 hospital) Tunisia: Mar 2007-Mar 2011	Children with or without PLS (hospitalized and not hospitalized). Range: 1d-11mo	120	108 (89.2) PICU: 71 (59.2)	8 (6.6) All < 6 mo	3%	MV: 18 (15.0)	Pulmonary hypertension: 1 (0.8)
Children < 6 months							
G. Noel et al., 2021 [19]: Prospective (2 hospitals) Iran: Nov 2016-May 2019	Children with PLS (most hospitalized) Median (IQR): 2.0 (1.3–2.8) mo. Range: 8 d-6 mo	40[A]	39 (97.5)	1 (2.5)	-	-	-
F. Birru et al., 2021 [38]: Retrospective (2 hospitals) Oman: Jan 2013-Dec 2018	Children with confirmed pertussis (hospitalized) Median: 8 (IQR 5–12) wks	157	157 (100.0) Median (IQR): 5 (3–8) d PICU: 19 (12.1) Median (IQR): 6 (4–16)d	1 (0.6)	3 (1.9)	MV: 9 (5.7)	• Pulmonary hypertension: 1 (0.6) • Inotropes: 7 (4.5) • Hyperhydration: 3 (1.9) • Exchange transfusion: 4 (3.3)
Children < 3 months							
A. Bouziri et al., 2010 [37]: Retrospective (1 hospital) Tunisia: 2006–2008	Infants < 3 mo admitted to the PICU for severe acute respiratory failure.	10	10 (100.0) PICU: 10 (100.0)	9 (90.0)	4 (40.0)	• MV: 10 (100.0) • HFV: 3 (30.0)	• Pneumomediastinum: 1 (10.0) • Nitric oxide: 6 (60.0)
S. Omer et al., 2016 [44]: Prospective Pakistan: Feb 2015-Apr 2016	Infants enrolled at ages up to 10 wks and infants born to women enrolled on or after 27 wks' gestation or mothers who gave birth within the prior 72 h; followed through 18 wks of age.	8	0	1 (12.5)	-	-	--

Abbreviations: CAP Community-acquired pneumonia, *d* days, *EU* Emergency unit, *HDU* high dependency unit, *HFV* High-frequency ventilation, *IQR* Interquartile range, *Mo* Months, *MV* Mechanical Ventilation, *NA* Not available, *No*. Number, *PICU* Pediatric Intensive Care Unit, *PLS* Pertussis-like syndrome, *Wks* weeks, *Y* years

A: Confirmed by culture or PCR. B: Confirmed by culture. C: Confirmed by culture and/or PCR. D: Confirmed by culture followed by PCR in infants, which is consistent with global reports of critical pertussis in infants who have not yet completed their primary vaccination series [58–60]. These complications lead to significant healthcare resource utilization, including extended hospital stays and intensive care unit admissions [61, 62]. The financial and logistical burden on healthcare systems is substantial, emphasizing the importance of preventive measures such as vaccination. High mortality rates were observed in infants admitted to the PICU with pertussis. The predominance of severe outcomes in hospital-based studies further emphasizes the need for enhanced preventive strategies targeting this high-risk population.

The high hospitalization rates observed in the EMR align with data from other regions, such as North America and Europe, where infants under six months also experience the highest rates of hospitalization and complications from pertussis [53, 55, 63]. This vulnerability is attributed to the incomplete vaccination status of infants in this age group, who rely heavily on maternal antibodies for protection [64]. Extended hospital stays and intensive care admissions place a substantial burden on healthcare systems, both financially and logistically.

A major finding of this review is the lack of research and implementation of maternal pertussis vaccination programs in the EMR, with only one study from Saudi Arabia addressing this issue. This gap is concerning, given the proven effectiveness of maternal vaccination in reducing pertussis incidence and severity in infants, as demonstrated in countries such as the United States, the United Kingdom, and Australia [7]. The single study from Saudi Arabia underscores the low awareness and acceptance of maternal vaccination in the EMR, which contrasts with higher uptake rates in regions where maternal vaccination programs are well-established [65]. This highlights the need for targeted public health campaigns to educate healthcare providers and pregnant women about the benefits of vaccination during pregnancy. Implementing successful models from other regions could significantly reduce the disease burden in the EMR.

Countries that have implemented comprehensive vaccination programs, including maternal vaccination, have seen a reduction in these severe outcomes, including the death of infants from pertussis [7, 66]. Efforts in other regions have shown that enhancing pertussis vaccination coverage, including maternal vaccination during pregnancy, can significantly reduce disease burden among infants [7, 55, 64, 66, 67] underscoring the need for similar efforts in the EMR.

We categorized the studies by their design to determine the impact of study design on the reported outcomes. Cohort studies generally provided more comprehensive data on incidence and vaccination status than other study types. We investigated differences in pertussis incidence and outcomes based on the populations studied, such as general populations versus high-risk groups, including hospitalized infants. High-risk groups often exhibited higher incidence rates and more severe disease outcomes. The predominance of hospital-based studies highlights the severe complications often associated with pertussis in this vulnerable age group, including respiratory distress, seizures, and mortality.

Additionally, studies were grouped based on reported vaccination coverage rates to examine the impact of vaccination on pertussis incidence and severity. Areas with higher vaccination coverage generally reported lower incidence rates and less severe disease outcomes, although this was not universally consistent.

The study has a number of strengths. To the best of our knowledge, this is the first comprehensive systematic review in the EMR that evaluates the impact of pertussis on infants. It fills a significant gap in the existing literature and provides a basis for future research and public health initiatives. The study used a thorough and systematic search strategy across multiple databases, ensuring that a wide range of studies was included, which increased the reliability of the findings. Additionally, by highlighting the substantial gap in studies on maternal pertussis vaccination in the EMR, this review draws attention to an important area for future research and intervention. This finding is crucial for guiding public health efforts to promote maternal vaccination.

However, the review also faced several limitations that should be acknowledged. First, the variability in study designs among the included studies, such as prospective, retrospective, and cross-sectional, may have introduced heterogeneity in the findings. Studies based on hospital or clinic-based data are more likely to overrepresent severe cases, potentially skewing the understanding of pertussis epidemiology in the region. Second, while some studies relied on confirmatory diagnostic methods such PCR or culture, others were based solely on clinical diagnosis, which may have led to under- or overestimation of pertussis cases. This inconsistency may also affect comparisons across studies and the overall synthesis of findings. Third, there is potential for selection bias. Many of the included studies focused on hospitalized patients, which excludes mild or asymptomatic cases of pertussis that are often managed in outpatient settings or remain undiagnosed. Additionally, countries with more robust healthcare systems and diagnostic capabilities may have higher reported incidence rates, creating regional disparities in the data. Publication bias may also have impacted the findings of this study. Relevant studies published in non-indexed journals or in languages other than English may have been missed despite comprehensive search strategies. Moreover, data from several countries in the EMR are lacking, limiting the generalizability of the findings. Finally, the lack of economic data represents a critical limitation. While this study aimed to examine the economic burden of pertussis and the effect of maternal pertussis vaccination, no relevant data were identified in the included studies. This highlights a significant gap in the literature and underscores the need for future research on the financial impacts of pertussis and the cost-effectiveness of preventive strategies such as maternal vaccination.

Despite these limitations, this systematic review provides valuable insights into the burden of pertussis and maternal vaccination practices in the EMR, laying the groundwork for future research and public health initiatives.

Conclusion

This systematic review underscores the substantial burden of pertussis among young infants in the EMR and the notable lack of data on pertussis vaccination during pregnancy. The findings indicate the need for improved surveillance, targeted public health interventions, and research to address these gaps and protect vulnerable infant populations.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-21329-y.

Supplementary Material 1.
Supplementary Material 2.
Supplemenatry Material 3.
Supplementary Material 4.
Supplementary Material 5.

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Authors' contributions
RS contributed to the conception of the study, conducted the literature review, performed the screening of the title, abstract, and full text, and was involved in data abstraction and interpretation. Additionally, RS played a major role in writing the manuscript. YK contributed to the conception of the study and the literature review, interpreted the data, and was a key contributor to the manuscript writing. FM contributed to the conception of the study and the interpretation of data and was a significant contributor in revising the manuscript. FL was involved in the conception of the study and data interpretation and also played a major role in revising the manuscript. EM contributed to the conception of the study and interpretation of data and was a key contributor to the manuscript revision. NH participated in the conception of the study and data interpretation and also contributed significantly to revising the manuscript. All authors read and approved the final version of the manuscript.

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Data availability
All data generated or analyzed during this study are included in this published article and its supplementary information files. The title and abstract, full-text screening criteria, data extracted from included studies, and any other additional materials used in the review during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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