Khales et al. BMC Pulmonary Medicine (2025) 25:135
https://doi.org/10.1186/s12890-025-03587-z

BMC Pulmonary Medicine

SYSTEMATIC REVIEW

Open Access

Prevalence of respiratory viruses in children with respiratory tract infections during the COVID-19 pandemic era: a systematic review and meta-analysis

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Abstract

Background and aims The evaluation of the spread of respiratory viruses in the context of the COVID-19 pandemic is required to understand how SARS-CoV-2 may have impacted the spectrum of respiratory viruses among children. Our study aimed to examine the viral etiology of respiratory infections other than SARS-CoV-2 in children during the COVID-19 pandemic.

Methods Three databases including PubMed, Scopus, and Web of Science were systematically searched from 2020 to 2023 to assess the pooled prevalence of respiratory viruses in different regions, types of patient care, and types of respiratory disease.

Results A total of 68 studies were included in this systematic review and meta-analysis. Rhinovirus/Enterovirus (29.1%) and Respiratory syncytial virus (11.3%) were among the most common viruses among children with respiratory infections during the COVID-19 pandemic. In the case of patients younger than 5 years old, Rhinovirus/Enterovirus (36.2%) were the most prevalent viruses among all types of respiratory diseases. Also, Rhinovirus/Enterovirus were the most common viruses in the case of acute respiratory infection (26.1%), upper respiratory tract infection (21.0%), pneumonia (97.3%), and severe acute respiratory infection (54.7%). The most common viruses detected among inpatient cases were Rhinovirus/Enterovirus (47.4%) and Respiratory syncytial virus (14.9%). The prevalence of Influenza A + B viruses and Metapneumovirus among inpatients was also significantly higher than among outpatients.

Conclusion The high prevalence of viruses such as Rhinovirus/Enterovirus and Respiratory syncytial virus in various respiratory conditions, shows the requirement for enhanced surveillance, vaccination, and treatment strategies. The significance of Influenza viruses and metapneumovirus in inpatient settings delineates the importance of prioritizing them in future preventive measures such as vaccine development to minimize respiratory infection-associated hospitalization.

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Keywords Respiratory infections, Virus, Pediatrics, Epidemiology, Children, COVID-19

Introduction

Millions of people throughout the world are diagnosed with respiratory tract infections every year. Respiratory tract infections are a major burden on healthcare systems, causing an estimated 4 million fatalities annually across all age groups and 20% of mortality in pediatric patients [1]. Respiratory infections can be attributed to several pathogens such as viruses, bacteria, and fungi, although the majority of respiratory infections are of viral origin. Viruses are one of the most prevalent causes of respiratory tract infections, which can lead to serious morbidity and mortality in children. Rhinovirus/Enterovirus, Respiratory syncytial virus, Influenza A and B viruses, Adenoviruses, Bocavirus, Metapneumovirus, Parainfluenza viruses, Coronaviruses, and Paraechovirus are identified as important pathogens in the etiology of respiratory illnesses [2, 3].

The coronavirus disease 2019 (COVID-19) pandemic has been ongoing since December 2019. A range of non-pharmaceutical interventions (NPIs) were quickly launched and used to prevent the spread of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) worldwide. The categories of NPIs included wearing face masks, restricting social gatherings, maintaining hand hygiene, and home isolation, which were crucial in reducing the spread of SARS-CoV-2 [4]. These efforts, which were initially intended to reduce the impact of the COVID-19 pandemic, also influenced the transmission dynamics of other viral respiratory infections [5]. Many studies have shown that following the COVID-19 pandemic, the rate of acute respiratory infections (ARI) in children dropped [6–8]. This reduction was advantageous in the short term since it avoided adding to the already excessive number of hospital wards and intensive care units (ICUs) during the COVID-19 pandemic. Nonetheless, infections with common respiratory viruses other than SARS-CoV-2 usually happen in early life and are nearly inevitable in the early years. Lack of immune activation owing to NPIs generates an "immunity debt" or an "immunity gap" that could have detrimental effects after the pandemic is under control [9].

Long-term worldwide surveillance of viral respiratory infections is necessary. Epidemiological studies, particularly disease etiology, continue to be crucial for directing pediatricians in diagnosing and treating respiratory infectious disorders in children. In this systematic review and meta-analysis, we aimed to specifically investigate the viral etiology of respiratory infections other than SARS-CoV-2 amongst children during the COVID-19 pandemic by considering various factors such as age group, respiratory conditions, and geographical distribution.

Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline served as the foundation for this systematic review and meta-analysis approach [10].

Search strategy

To discover relevant papers, a systematic literature search was undertaken utilizing three electronic databases including PubMed, Scopus, and Web of Science. The literature search was restricted to the period between January 1, 2020 to October 18, 2023. Table S1 provides information about the search terms for each database. We manually searched the reference lists of pertinent articles to find further research that met the eligibility criteria. For data management, the systematic literature search was loaded into EndNote software version X8 (Thomson Reuters, California, USA).

Selection criteria

Studies were considered qualified if they reported: (1) data related to the prevalence of respiratory viruses other than SARS-CoV-2 among children less than 18 years with respiratory symptoms published in the English language in peer-reviewed journals; (2) the prevalence of respiratory viruses' genomes in respiratory samples; (3) sample collection during COVID-19 pandemic; (4) studies detecting respiratory viruses' genomes by polymerase chain reaction (PCR)-based methods; (5) studies detecting the prevalence of respiratory viruses among inpatients and outpatients; (6) original articles and short communications with sufficient data.

Studies that met any of the following criteria were excluded: (1) the prevalence of respiratory virus infections among adult patients with respiratory symptoms; (2) the prevalence of respiratory virus infections among children with underlying conditions such as cancer, sickle cell anemia, cystic fibrosis (CF), asthma, down syndrome, and immunocompromised patients; (3) cohort or prospective studies investigating the incidence of respiratory virus infections among children with respiratory symptoms; (4) samples other than respiratory specimens such as blood; (5) detection of respiratory viruses by assays other than PCR-based methods such as enzyme-linked immunosorbent assay; (6) Sample collection before January 2020; (7) studies including patients with non-respiratory symptoms or asymptomatic patients; (8) letters, case series, notes, comments, reviews, case reports, posters, and conference abstracts; (9) articles published in languages other than English.

Data extraction and quality assessment

Title and abstract of all of the papers were separately investigated by two reviewers and irrelevant studies were eliminated. Full texts of the selected papers were obtained and further read by both reviewers and papers that did not meet the inclusion criteria were excluded. Eventually, any disparities in the data extraction were solved by a third reviewer. The strengthening the reporting of observational studies in epidemiology (STROBE) was used to assess quality of the included papers [11, 12]. The mentioned checklist contains twelve questions that address different methodological approaches. Those studies with a validity score of at least 8 out of the maximum of 12 were considered eligible for inclusion in the main meta-analysis. One reviewer extracted the data from each eligible article: first author's last name, year of publication, year of sampling, study location, sample size, age ranges of patients, number of cases with positive results of respiratory viruses, types of patient care, and type of respiratory disease. The retrieved data were entered into a pre-designed Excel spreadsheet (Microsoft Corporation, Redmond, Washington, USA).

Statistical analysis

We pooled the prevalence of respiratory viruses in children with respiratory tract infections During the COVID-19 pandemic era using the metaprop package [13]. The summary prevalence with 95% CI was obtained using the random effects model. Cochran's Q test was used to identify the heterogeneity of the results and it was quantified using the I^2 statistics. I^2 statistic > 50% or Q statistics with $P < 0.10$ were considered as statistically significant between study heterogeneity [14]. Subgroup analysis based on the virus type, geographical region, disease type, and patient care setting, was performed to explore possible sources of heterogeneity. Level of statistical significance was less than 0.05 for all tests, except for heterogeneity test that were set at less than 0.1. All statistical analyses were done using Stata 14.1 (Stata Corp, College Station, TX, USA).

Results

Literature search

During the initial search, 72,768 papers were identified, and no further papers were discovered by manually examining the reference lists of pertinent research. A total of 21,649 duplicate papers were initially removed, and 50,925 additional papers were removed after a manual check of titles and abstracts. After a thorough evaluation of the full text of the remaining 194 papers to determine their eligibility for the meta-analysis, 123 of them were removed. According to the modified STROBE checklist, 68 publications were deemed to be of good quality (scoring of 8 or higher), with 3 papers were failed to get a score of 8. Finally, this systematic review and meta-analysis contained 68 papers. An overview of the selection of relevant studies is depicted in Fig. 1.

Characteristics of included studies

A total of 68 studies were included in this systematic review and meta-analysis. The studies were published between 2021 and 2023. All of the studies focused on children under 18 years of age, though some specifically targeted younger populations, including infants and children under five years. ARI was the most common disease type investigated, followed by severe acute respiratory infection (SARI), lower respiratory infection (LRI), upper respiratory infection (URI), and pneumonia. Sample sizes varied considerably, ranging from as few as 52 participants in the smallest study [15] to 49,045 participants in the largest study [16]. The complete characteristics of all included studies can be found in Table 1.

Respiratory viruses in pediatric patients

The pooled prevalence of respiratory viruses among pediatric patients was highly variable across virus types. Rhinovirus/Enterovirus exhibited the highest pooled prevalence at 29.1% (95% CI: 22.3-36.4%) across 26 studies. Respiratory syncytial virus (RSV) followed with a prevalence of 11.3% (95% CI: 8.3-14.8%). Adenovirus also had a notable pooled prevalence of 4.3% (95% CI: 2.9-6.0%). HCoVs exhibited a combined prevalence of 3.2% (95% CI: 2.2-4.3%), with specific subtypes such as HCoV-NL63, HCoV-OC43, and HCoV-229E contributing relatively low prevalence rates individually. Influenza A + B viruses had a pooled prevalence of 2.2% (95% CI: 1.1-3.5%), while Parainfluenza viruses 1–4 showed a combined prevalence of 5.1% (95% CI: 3.6-6.7%). Less common viruses in children were Metapneumovirus (2.6%; 95% CI: 1.3-4.1%) and Bocavirus (2.8%; 95% CI: 2.0-2.8%). The prevalence of Human Cytomegalovirus (HCMV) was 25.1% (95% CI: 22.1-28.2%) (Table 2).

Prevalence by geographic region

For Rhinovirus/Enterovirus, Malaysia reported the highest prevalence (97.3%), while South Korea had the lowest (2.8%). HCoV-NL63 was most prevalent in Austria (15.6%), while many countries had a 0.0% prevalence. HCoV-OC43 was highest in Japan (4.0%) and lowest in South Korea (0.0%). For HCoV-229E and HCoV-HKU1, several countries including South Korea reported 0.0%. Belgium had the highest prevalence (16.1%) and Iran had the lowest (0.0%) of Adenovirus. For Parainfluenza viruses, Japan reported the highest prevalence (18.2%) while Poland reported 0.0%. For Influenza A virus, Bulgaria had the highest prevalence (17.7%), and several countries, including South Korea, reported 0.0%. However, for the Influenza B virus, Saudi Arabia reported the

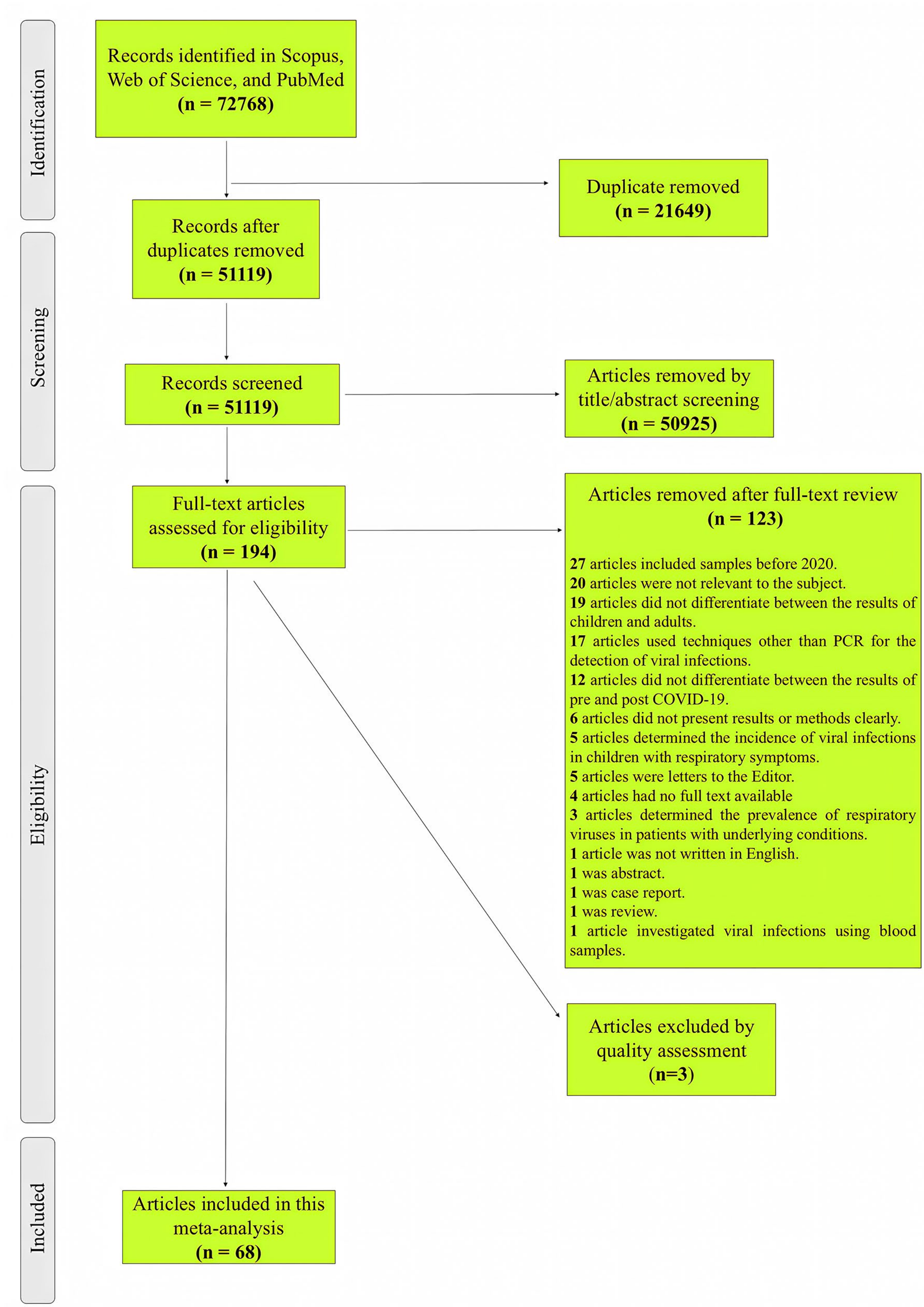

Fig. 1 Flowchart presenting the steps of literature search and selection

Table 1 Characteristics of studies included in the systematic review and meta-analysis

Author (Ref)	Publication Year	Location	Age Range	Type of disease	Sample size
Diesner-Treiber [17]	2021	Austria	Under 2 years	ARI	448
Agca [18]	2021	Turkey	Under 18 years	URI	248
Chen [1]	2021	Taiwan	Under 18 years	RI	92
Kanji [19]	2021	Canada	Under 18 years	RI	249
Kıymet [20]	2021	Turkey	Under 18 years	RI	513
Kondratiuk [21]	2021	Poland	Under 14 years	RI	999
Li [22]	2021	China	Under 14 years	ARI	3398
Cong [23]	2022	China	Under 14 years	ARI	232
Cui [24]	2022	China	Under 14 years	ARI	1508
Du [25]	2022	China	Under 12 years	ARI	1442
Garcia-Garcia [26]	2022	Spain	Under 14 years	ARI	14,640
Knudsen [27]	2022	Norway	Under 18 years	LRI	2102
Kozinska [28]	2022	Poland	Under 18 years	RI	103
Lee [29]	2022	South Korea	Under 5 years	URI	209
Lu [30]	2022	China	Under 18 years	RI	329
Maglione [31]	2022	Italy	Under 14 years	ARI	1763
Muruganandam [32]	2022	India	Under 15 years	SARI	105
Nenna [33]	2022	Italy	Under 12 years	RI	587
Ng [5]	2022	Malaysia	Under 12 years	Pneumonia	111
Ogunbayo [34]	2022	South Africa	Under 5 years	SARI	84
Orqueda [35]	2022	Argentina	Under 18 years	RI	619
Ouafi [36]	2022	France	Under 15 years	RI	3517
Perez [16]	2022	USA	Under 18 years	ARI	48,859
Perez [16]	2022	USA	Under 18 years	ARI	49,045
Perez [16]	2022	USA	Under 18 years	ARI	48,847
Quang [37]	2022	Vietnam	Under 15 years	Pneumonia	95
Shen [38]	2022	Belgium	Under 5 years	RI	93
Şık [39]	2022	Turkey	Under 18 years	ARI	327
Silva [40]	2022	Brazil	Under 18 years	RI	606
Soysal [41]	2022	Turkey	Under 3 months	Pneumonia	80
Tang [42]	2022	China	Under 15 years	RI	1559
Temte [43]	2022	USA	Under 18 years	ARI	497
Viart [44]	2022	France	Under 18 years	RI	836
Xiang [45]	2022	China	Under 14 years	ARI	1442
Xu [46]	2022	China	Under 18 years	LRI	632
Yakovlev [47]	2022	Russia	Under 18 years	ARI	864
Yildiz [48]	2022	Turkey	Under 18 years	RI	570
Zhang [49]	2022	China	Under 18 years	Pneumonia	375
Alaib [50]	2023	Saudi Arabia	Under 14 years	RI	205
Boggio [51]	2023	Argentina	Under 2 years	SARI	141
Darabi [15]	2023	Iran	Under 14 years	ARI	52
Edderdouri [52]	2023	Morocco	Under 15 years	ARI	178
Feng [53]	2023	China	Under 18 years	Pneumonia	1043
Fontes [54]	2023	Brazil	Under 10 years	Pneumonia	107
Fourie [55]	2023	Netherlands	Under 5 years	URI	88
Guo [56]	2023	China	Under 18 years	ARI	1225
Huang [57]	2023	China	Under 18 years	ARI	1442
Kang [58]	2023	India	Under 12 years	LRI	189
Kışlal [59]	2023	Turkey	Under 18 years	RI	207
Kitagawa [60]	2023	Japan	Under 5 years	RI	1181
Korsun [61]	2023	Bulgaria	Under 14 years	ARI	288
Kurskaya [62]	2023	Russia	Under 18 years	ARI	1130
Kurskaya [62]	2023	Russia	Under 18 years	ARI	972

Table 1 (continued)

Author (Ref)	Publication Year	Location	Age Range	Type of disease	Sample size
Li [63]	2023	China	Under 5 years	LRI	278
Li [63]	2023	China	Under 5 years	URI	278
Lin [64]	2023	China	Under 14 years	RI	2533
Lin [64]	2023	China	Under 14 years	RI	3668
Mai [65]	2023	China	Under 5 years	ARI	84
Mai [65]	2023	China	Under 5 years	ARI	73
Mohanty [66]	2023	India	Under 3 years	ARI	139
Moreira [67]	2023	Brazil	Under 13 years	ARI	128
Mun [68]	2023	South Korea	Under 18 years	RI	54
Naeem [69]	2023	Iraq	Under 5 years	LRI	158
Rankin [70]	2023	USA	Under 18 years	ARI	4881
Ren [71]	2023	China	Under 14 years	ARI	1964
Riepl [72]	2023	Austria	Under 3 years	ARI	815
Samuels [73]	2023	Sierra Leone	Under 2 years	ARI	502
Shi [74]	2023	China	Under 16 years	ARI	10,396
Steponaviciene [75]	2023	Lithuania	Under 18 years	ARI	5127
Tran [76]	2023	Vietnam	Under 5 years	RI	286
Xu [77]	2023	China	Under 14 years	ARI	112
Xu [77]	2023	China	Under 14 years	ARI	277
Xu [77]	2023	China	Under 14 years	ARI	322
Yavarian [78]	2023	Iran	Under 5 years	ARI	122
Zendehrouh [79]	2023	Iran	Under 16 years	RI	87
Zhao [80]	2023	China	Under 14 years	ARI	13,426

Table 2 Subgroup analysis of the prevalence of viral infections among pediatric patients with respiratory tract infection

Viruses	No of studies	Pooled prevalence (%) (95% CI)	Heterogeneity test I^2%, *p*-value
Rhinovirus	33	16.8 (11.5–22.7)	99.56%, $P=0.0000$
Enterovirus	10	2.9 (0.9-6.0)	97.04%, $P=0.0000$
Rhinovirus/Enterovirus	26	29.1 (22.3–36.4)	99.67%, $P=0.0000$
HCoV-NL63	17	0.7 (0.04–1.9)	93.48%, $P=0.0000$
HCoV-OC43	18	0.9 (0.3–1.8)	86.29%, $P=0.0000$
HCoV-229E	18	0.06 (0.0-0.2)	50.23%, $P=0.008$
HCoV-HKU1	16	0.03 (0.0-0.3)	78.53%, $P=0.0000$
MERS	7	0.0	0%, $P=0.92$
Human Coronaviruses	33	3.2 (2.2–4.3)	96.58%, $P=0.0000$
Adenovirus	52	4.3 (2.9-6.0)	99.12%, $P=0.0000$
Parainfluenza virus 1	22	0.3 (0.02–0.8)	90.71%, $P=0.0000$
Parainfluenza virus 2	22	0.03 (0.0-0.1)	48.15%, $P=0.006$
Parainfluenza virus 3	24	4.7 (2.8–7.1)	96.45%, $P=0.0000$
Parainfluenza virus 4	14	0.8 (0.4–1.5)	70.67%, $P=0.0000$
Parainfluenza virus 1–4	48	5.1 (3.6–6.7)	98.75%, $P=0.0000$
Influenza A	35	0.7 (0.2–1.4)	96.45%, $P=0.0000$
Influenza B	35	0.3 (0.06–0.8)	95.15%, $P=0.0000$
Influenza A + B	55	2.2 (1.1–3.5)	99.33%, $P=0.0000$
RSV	62	11.3 (8.3–14.8)	99.43%, $P=0.0000$
Metapneumovirus	49	2.6 (1.3–4.1)	99.18%, $P=0.0000$
Bocavirus	33	2.8 (2.0-3.8)	95.09%, $P=0.0000$
Paraechovirus	7	0.1 (0.0-0.7)	61.24%, $P=0.01$
HCMV	4	25.1 (22.1–28.2)	73.96%, $P=0.009$
EBV	2	3.4 (1.1–6.6)	0%, NA
HHV-6	2	17.6 (13.6–21.9)	0%, NA
VZV	1	1.0 (0.2-3.0)	NA, NA

highest prevalence (1.4%), and many countries showed 0.0%. South Africa reported the highest prevalence (47.6%) for RSV while Poland showed the lowest (0.0%). For Metapneumovirus, Morocco reported the highest prevalence (9.5%), and several countries such as Norway and South Korea, reported 0.0%. For Bocavirus, Argentina showed the highest prevalence (28.3%) and Brazil reported 0.0%. In the context of Paraechovirus, Belgium had the highest prevalence (5.3%) while many other countries, including India, reported no detectable prevalence. HCMV had its highest prevalence in China (26.6%) while South Korea reported the lowest (8.5%).

Prevalence by disease type

The most common viruses among ARI cases were Rhinovirus/Enterovirus, RSV, and Parainfluenza viruses 1–4 with a prevalence of 26.1%, 10.0%, and 3.6%, respectively. However, the lowest prevalences were observed for Bocavirus (2.1%) and Influenza A + B viruses (2.2%). Rhinovirus/Enterovirus prevalence in patients with URI was the highest (21.0%), while the lowest rate was observed for Influenza A + B viruses (1.9%). In patients with LRI, Rhinovirus (30.4%), RSV (7.2%), and Parainfluenza viruses 1–4 (7.0%) had the highest prevalence, while HCoVs (1.2%) and Bocavirus (1.3%) had the lowest prevalences. The most prevalent viruses among patients with pneumonia were Rhinovirus/Enterovirus (97.3%) and RSV (40.5%), while the lowest prevalences were observed for Metapneumovirus (0%) and Influenza A + B viruses (0.7%). Rhinovirus/Enterovirus (54.7%), Bocavirus (28.3%), and RSV (16.5%) were among the most common viruses detected in SARI patients. In contrast, Parainfluenza viruses 1–4 (3.5%) and HCoVs (4.2%) were detected in the lowest rates.

Prevalence by patient care setting

The most common viruses detected among inpatient cases were Rhinovirus/Enterovirus (47.4%) and RSV (14.9%). Rhinovirus/Enterovirus was also the most prevalent virus among outpatient cases with a rate of 35.3%, followed by HCoVs (10.6%). The prevalence of Influenza A + B and Metapneumovirus among inpatients was significantly higher than among outpatients (Supplementary Tables).

Prevalence among children aged under 5 years

For Rhinovirus, six studies reported a pooled prevalence of 22.7% while for Enterovirus, three studies found a pooled prevalence of 4.8%. Rhinovirus/Enterovirus combined were investigated in eight studies that reported a pooled prevalence of 36.2%. The overall pooled prevalence for HCoVs was 5.3% (95% CI: 2.7–8.6) in nine studies. HCoV-NL63 had a prevalence of 3.0%, while HCoV-OC43 had 1.2%. HCoV-229E was not detected in patients under 5 years. Fourteen studies reported a prevalence of 5.8% for Adenovirus. The overall prevalence of Parainfluenza viruses was 9.3% in 11 studies, with Parainfluenza virus 3 being the most prevalent at 6.9%. In the case of RSV, sixteen studies revealed a pooled prevalence of 13.8%. Eight studies showed a pooled prevalence of 6.6% for Bocavirus. Finally, only one study reported the prevalence of HCMV in young children, with a prevalence of 20.4% (Table 3).

Discussion

The findings of this meta-analysis provide a comprehensive overview of the global prevalence of respiratory viruses since 2020. The results offer valuable insights into the epidemiology of these viruses in different regions, patient populations, and disease types. The substantial variability in prevalence rates, both between and within regions, underscores the complex nature of respiratory viral infections and highlights the influence of local factors such as healthcare infrastructure, public health policies, and diagnostic practices.

The considerable geographic variability in the prevalence of respiratory viruses suggests that local environmental, social, and healthcare factors play significant roles in shaping viral epidemiology. Countries such as Malaysia and South Africa reported some of the highest prevalence rates, while countries such as South Korea and Poland consistently reported much lower rates for multiple viruses. These disparities could be influenced by several factors, including differences in diagnostic capabilities, climate, and healthcare access. For instance, higher prevalence rates in low- and middle-income countries, such as Malaysia and South Africa, may reflect greater exposure to environmental risk factors, limited access to healthcare, and possible delays in diagnosis and treatment, which helps respiratory viruses to be transmitted to other individuals. On the other side, the lower prevalence in countries such as South Korea may indicate the success of stringent public health measures, advanced healthcare systems, and widespread vaccination programs. This variability highlights the importance of implementing public health interventions in local contexts.

The findings demonstrate that the type of respiratory illness significantly influences the prevalence of different viruses. RSV and Rhinovirus/Enterovirus were more prevalent in severe disease presentations such as pneumonia and SARI, while HCoVs and Influenza viruses generally exhibited lower prevalence across the spectrum of disease severity. For example, RSV showed a high prevalence in pneumonia cases, indicating its strong association with more severe LRI. This association between certain viruses and severe disease shows the importance of early diagnosis and targeted treatment, especially in

Table 3 Subgroup analysis of the prevalence of viral infections among pediatric patients aged under 5 years with respiratory tract infection

Viruses	No of studies	Pooled prevalence (%) (95% CI)	Heterogeneity test I^2%, *p*-value
Rhinovirus	6	22.7 (9.2–39.9)	95.67%, $P=0.0000$
Enterovirus	3	4.8 (0.0-34.5)	NA
Rhinovirus/Enterovirus	8	36.2 (26.1–47.0)	97.26%, $P=0.0000$
HCoV-NL63	6	3.0 (0.001-8.7)	95.99%, $P=0.0000$
HCoV-OC43	6	1.2 (0.001-3.0)	83.90%, $P=0.0000$
HCoV-229E	6	0.0 (0.0-0.03)	0%, $P=0.4$
HCoV-HKU1	5	0.3 (0.0-1.9)	84.41%, $P=0.0000$
MERS	3	0.0 (0.0-0.06)	NA
Human Coronaviruses	9	5.3 (2.7–8.6)	92.25%, $P=0.0000$
Adenovirus	14	5.8 (3.8–8.3)	88.48%, $P=0.0000$
Parainfluenza virus 1	9	0.5 (0.0-1.4)	78.75%, $P=0.0000$
Parainfluenza virus 2	9	0.2 (0.0-0.8)	71.37%, $P=0.0000$
Parainfluenza virus 3	9	6.9 (2.9–12.3)	94.97%, $P=0.0000$
Parainfluenza virus 4	7	0.7 (0.02-2.0)	77.15%, $P=0.0002$
Parainfluenza virus 1–4	11	9.3 (5.5–14.0)	94.96%, $P=0.0000$
Influenza A	11	0.7 (0.02–2.2)	86.51%, $P=0.0000$
Influenza B	11	0.8 (0.06–2.1)	84.33%, $P=0.0000$
Influenza A + B	13	2.5 (0.7–5.1)	94.12%, $P=0.0000$
RSV	16	13.8 (7.8–21.2)	97.55%, $P=0.0000$
Metapneumovirus	13	2.7 (0.8–5.5)	94.60%, $P=0.0000$
Bocavirus	8	6.6 (2.5–12.2)	90.95%, $P=0.0000$
Paraechovirus	3	0.6 (0.0-4.4)	NA
HCMV	1	20.4 (12.7–30.0)	NA
EBV	1	0.7 (0.02–3.9)	NA
HHV-6	1	12.5 (8.9–17.0)	NA
VZV	1	1.0 (0.2-3.0)	NA

high-risk populations. It also depicts the need for vaccines and therapeutic interventions to reduce the burden of these viruses, especially RSV, which remains a significant cause of morbidity and mortality worldwide among both children and adults [81, 82].

A clear distinction in viral prevalence was observed between inpatient and outpatient settings. Respiratory viruses such as RSV and Rhinovirus/Enterovirus were more prevalent among hospitalized patients. This suggests that these viruses contribute significantly to severe respiratory illnesses that require hospitalization. On the other part, although the viral prevalence in outpatient settings was lower, the findings still point to a substantial burden of respiratory viral infections in the general population. This highlights the need for comprehensive primary care strategies to manage and treat these infections early to prevent progression to more severe diseases that could necessitate hospitalization and even cause death.

The results reveal distinct prevalence patterns for each virus and also reflect their unique epidemiological characteristics. For instance, Rhinovirus and Enterovirus exhibit significant prevalence in both ARI and SARI disease spectrums, with Malaysia and South Africa reporting the highest rates. RSV, on the other hand, was predominantly associated with severe respiratory conditions such as pneumonia, with particularly high prevalence in Italy and South Africa. While the prevalence of influenza A and B was generally low in most countries, it was notable in certain regions such as Bulgaria. This suggests that, although overshadowed by the COVID-19 pandemic, influenza still remains a relevant public health concern that requires continued surveillance and vaccination plans. We recommend further surveillance, preventive, and treatment measures to keep the prevalence of influenza viruses low to minimize the risk of commencement of outbreaks in the future.

Human coronaviruses, particularly the less commonly researched strains including HCoV-NL63, HCoV-OC43, and HCoV-229E, were also observed at low prevalence levels, though their role in respiratory infections remains important, particularly in the context of co-infections or during periods of heightened respiratory illness. Their relatively low prevalence across the studies likely reflects the overwhelming focus on SARS-CoV-2, which may have masked the detection and reporting of other coronaviruses during the pandemic.

The findings on pediatric patients aged under 5 years reveal significant viral burden, particularly from Rhinovirus/Enterovirus, RSV, and Adenovirus. The prevalence of Rhinovirus/Enterovirus and RSV shows their important role in pediatric respiratory infections, particularly in young children with immature immune systems. These results align with the high rates of hospitalizations often associated with RSV in this age group [83, 84]. The detection of multiple viral agents in children under 5 years and given the vulnerability of this age group, researchers, clinicians, and governing bodies should realize the need for targeted public health interventions, particularly in developing countries where access to healthcare may be limited. Moreover, since breastfeeding showed effectiveness in reducing severe disease by respiratory viruses in infants [85–87], we recommend healthcare workers and policy makers to advocate for breastfeeding to reduce the burden of respiratory infection-related hospitalization in infants.

One of the important findings of this study is the prevalence of HCMV in patients with respiratory infections. HCMV exhibited notable geographic differences, with China and Belgium reporting higher prevalence rates while South Korea had a lower prevalence. This variation could be due to differing healthcare practices, diagnostic criteria, or population-specific factors. HCMV is ubiquitous and is often a threat to immunocompromised patients [88] and might be more prevalent in regions with higher rates of HIV or organ transplantation. Therefore, the exact reasons for these regional variations require further investigation. These findings suggest that the burden of HCMV could be underreported in some regions, particularly in lower-income countries where access to diagnostic testing may be limited. It should also be noted that while there were very few studies on HCMV, the relatively high prevalence makes this virus a potent candidate to be considered in future epidemiologic studies on agents of respiratory infections.

The results, which cover the period since 2020, coincide with the global COVID-19 pandemic, which had profound impacts on respiratory virus transmission. Widespread public health measures, including lockdowns, mask mandates, and social distancing, likely contributed to the reduction in transmission of respiratory viruses such as influenza and RSV in many regions. For example, the overall low prevalence of influenza A and influenza B may reflect these pandemic-related interventions, which disrupted the typical seasonality and circulation patterns of these viruses. Studies from around the world showed that those public health measures could successfully reduce the prevalence of respiratory viruses [89–91]. This indicated the effectiveness of public health measures to tackle future epidemics and pandemics. Noteworthy, the high prevalence of certain viruses, such as Rhinovirus and RSV illustrates the rapid return of viral transmission. This pattern has important implications for post-pandemic public health planning, particularly in regions where healthcare systems are still recovering from the strain of managing COVID-19 cases.

The findings of this meta-analysis show the ongoing global burden of respiratory viruses. The high prevalence of certain viruses, particularly among severe cases in inpatient settings highlights the need for robust public health interventions. Vaccination programs targeting RSV and influenza, as well as continued investment in rapid diagnostic tools, are critical to mitigating the burden of respiratory infections. Furthermore, the geographic variability in the prevalence of viruses indicates the need for region-specific strategies that take into account local epidemiological patterns, healthcare infrastructure, and population health. Public health authorities should prioritize vigorous respiratory virus surveillance, particularly in low- and middle-income countries, where healthcare access and diagnostic capacity may be limited.

Recently, the prevalence of respiratory viruses among pediatric patients was analyzed by Dallmeyer et al. [92]. However, our study offers advantages in methodology and findings. While their study analyzed all reports using various viral testing methods, our study exclusively focuses on molecular epidemiologic studies, which reduces heterogeneity due to various sensitivity and specificity of other methods. Also, patients' age was included in our study. Our study stratified prevalence by age to further assess the prevalence among children under five years, a subgroup that have shown to be highly vulnerable to respiratory infections [93, 94] while the study by Dallmeyer et al. included children aged 12 years old and younger [95]. This makes them an important target group in the epidemiologic studies on respiratory infections. Moreover, our inclusion of viruses such as Paraechovirus and HCMV and detailed regional analysis of viruses provides a more extensive understanding of viral prevalence across inpatient and outpatient settings.

The are some limitations for this study that should be acknowledged. First, the high heterogeneity across some studies may limit the generalizability of the pooled estimates. Second, the focus on published studies may introduce publication bias, as studies with significant findings are more likely to be published. Also, the impact of COVID-19 on the epidemiologic status of other respiratory viruses makes the findings from 2020 onwards unable to fully reflect typical seasonal or epidemiological trends. The third limit was the lack of reports from some countries. Conducting studies in those countries can be helpful to have a better epidemiologic pattern for various respiratory viruses.

Conclusion

This meta-analysis study highlights the significant global burden of respiratory viruses in children, with notable variability across regions, disease types, and care settings. The high prevalence of viruses such as Rhinovirus/Enterovirus and RSV particularly in severe cases, shows the requirement for enhanced surveillance, vaccination, and treatment strategies. It shall be noted that future research should focus on addressing the gaps in standardization and data collection to improve the accuracy of global respiratory virus prevalence estimates and inform targeted public health interventions.

Abbreviations

COVID-19	Coronavirus disease 2019
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
NPIs	Non-pharmaceutical interventions
ARI	Acute respiratory infection
ICUs	Intensive care units
PRISMA	The Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PCR	Polymerase chain reaction
CF	Cystic fibrosis
STROBE	The strengthening the reporting of observational studies in epidemiology
SARI	Severe acute respiratory infection
LRI	Lower respiratory infection
URI	Upper respiratory infection
RSV	Respiratory Syncytial virus
HCOVs	Human Coronaviruses
HCMV	Human Cytomegalovirus

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12890-025-03587-z.

Supplementary Material 1

Acknowledgements

Clinical trial number: not applicable.

Author contributions

P.K and A.T designed the study. P.K and S.G did the systematic search. H.S performed the statistical analysis. MHR. A.M and A.T prepared the draft. All authors participated in reviewing and editing the final manuscript.

Funding

The research received no fundings.

Data availability

The datasets used and/or analysed 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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Received: 10 December 2024 / Accepted: 7 March 2025
Published online: 25 March 2025

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