BMJ Open Ophthalmology

Prevalence of dry eye disease among children: a systematic review and meta-analysis

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To cite: Zou Y, Li D, Gianni V, *et al*. Prevalence of dry eye disease among children: a systematic review and meta-analysis. *BMJ Open Ophthalmology* 2025;**10**:e002014. doi:10.1136/bmjophth-2024-002014

► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/bmjophth-2024-002014).

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Received 22 October 2024
Accepted 21 January 2025

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ABSTRACT

Background Dry eye disease (DED) is a multifactorial disorder of the tear film and ocular surface instability that causes ocular discomfort and visual impairment. The increasing use of digital devices and changing lifestyle patterns have raised concerns about a potential rise in DED among children. Understanding the prevalence of paediatric DED is crucial for developing effective diagnostic and management strategies tailored to this vulnerable population.

Method An exhaustive literature search was performed on several databases covering the period from 1 January 2001 to 1 April 2024. Prevalence estimates of DED were combined using random effects models, and heterogeneity sources were explored through subgroup and regression analyses.

Results Our literature search identified 7309 articles, of which 41 articles, representing 42 study cohorts (48 479 participants) included in the systematic review. The estimated prevalence of DED among children was 23.7% (95% CI 18.5% to 28.9%). The prevalence of DED by different diagnostic criteria (clinical signs vs reported symptoms by questionnaire) was 16.6% (95% CI 13.7% to 19.5%; 26 studies; 27 107 children) vs 34.6% (95% CI 23.7% to 45.6%; 16 studies; 21 372 children; p<0.01), respectively. The prevalence of DED after the COVID-19 pandemic outbreak was 44.1% (95% CI 25.5% to 62.7%; 8 studies; 9163 children), which was significantly higher than the 18.7% (95% CI 15.6% to 21.9%; 34studies, 39 316 children; p=0.01) before the COVID-19 outbreak. High between-study heterogeneity was noted (I^2>92%). In meta-regression analysis, the prevalence of DED among children increased by 7.1% with each 10° decrease in latitude (p=0.015), and by 10.2% with each 10° increase in mean annual temperature (p=0.024).

Conclusions DED is common in children up to 18 years of age and poses a significant disease burden. Standardisation of the diagnosis of DED in children and further study of other risk factors are needed to fully explain the epidemiology of DED in children.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Currently published reviews do not have publications related to dry eye disease (DED) among children; therefore, it is imperative to conduct a literature review to gain a comprehensive understanding of DED among children.

WHAT THIS STUDY ADDS

⇒ Our findings show that the prevalence of DED in children is close to the prevalence of DED in adults. The prevalence of DED in children was associated with study context, diagnostic modality, COVID-19, weather and geographical location.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The results of the study help to understand the global prevalence of DED in children. It emphasises the need to focus on children's ocular surface health and to establish an age-appropriate set of diagnostic criteria for children.

INTRODUCTION

Dry eye disease (DED) is a multifactorial ocular surface disorder characterised by loss of tear film homoeostasis and may result in various ocular symptoms and visual disturbances.[1] DED pathology can significantly affect an individual's visual function, quality of life[2] and work productivity[3] and has been associated with lower health utility.[4] Moreover, DED can have considerable negative personal and socioeconomic repercussions.[5] This includes direct economic costs, such as medical professional visits and treatment costs and intangible personal costs, including impaired social, emotional and physical function.[6]

According to the Tear Film and Ocular Surface Society (TFOS), the global prevalence of DED ranges between 5% and 50% in the general population, and epidemiological studies vary widely in terms of geographical and age differences, and diagnostic criteria.[7] It is currently agreed that the prevalence of DED is higher in people over 50 years of age, especially among postmenopausal women.[8] The prevalence of DED may be higher in Asia than in other regions.[9] It has been reported that lower DED prevalence is associated with

higher latitude and relative humidity and a temperate climate.[10]

The prevalence and contributing mechanisms in DED among children are influenced by multiple factors related to congenital, autoimmune and inflammatory disorders, and the condition may also be caused or exacerbated by factors such as the living environment.[11] With the popularisation of computers and smartphones, associated exposure to electronic screens that emit blue light and decreased blink rates have led to an increase in the prevalence of DED.[12] Furthermore, during the COVID-19 pandemic, children around the world stayed at home and studied online, leading to an increase in complaints of dry eyes and visual fatigue.[13] In addition, wearing face masks, a widespread public health intervention during the pandemic, is a risk factor for DED. Many children had difficulty finding a mask that fits well and was easy to wear correctly.[14]

The epidemiology and pathological processes of DED in children have not been described as comprehensively as in adults.[15] Therefore, we conducted a systematic review and meta-analysis to understand the current profile associated with childhood DED. Accurate estimation of the current prevalence of paediatric DED is essential for developing appropriate strategies to promote paediatric ocular surface health on a global scale.

Methods

We performed a systematic review and meta-analysis following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist guidelines (online supplemental appendix 1).[16] Data extraction, risk of bias assessment and statistical analyses were conducted following the methods outlined in the Cochrane Handbook for Systematic Reviews of Interventions. The review protocol was registered on PROSPERO (CRD42023343999) on 24 April 2023. Following the first review, we adjusted our analysis plan and updated the registration on 18 September 2024. Our revised inclusion criteria now focus on cross-sectional studies involving children under 18 years of age. We added an analysis of children wearing contact lenses, along with subgroup analyses based on study setting, DED diagnostic methods, climate zones and regions (Asian vs non-Asian). Additionally, we included a regression analysis of climate factors (temperature, latitude, humidity and rainfall) and prevalence. The final literature search was conducted on 1 April 2024.

Search strategy

We searched two Chinese databases (WANFANG Data and China National Knowledge Infrastructure) and five English bibliographic databases (PubMed, Embase, Ovid, Web of Science and Cochrane Library) from 1 January 2001 to 1 April 2024. No language restrictions were applied. Next, a snowball search was performed from the reference lists in eligible articles to identify additional potentially relevant studies. A detailed search strategy is in online supplemental appendix 2.

Inclusion and exclusion criteria

Studies satisfying the following criteria were considered eligible for inclusion: (1) Eligibility determined by the reported age range of participants, studies enrolling children or adolescents with a reported age range primarily under 18 years. For school/community-based studies (primary, middle and high schools), participants over 18 years of age were included only if they constituted less than 5% of the total population; (2) Cross-sectional design and (3) Original reports published in peer-reviewed journals. For multiple publications of the same study, the one best meeting eligibility criteria was retained for analysis.

Studies were excluded if they met any of the following criteria: (1) lack of a clearly described method of DED assessment and diagnosis.

Data collection and quality assessment

Title and abstract screening and full-text evaluation were independently carried out by two reviewers (YZ and ZZ) based on the above eligibility criteria. Any differences in opinions were discussed to reach a consensus. A third reviewer (DL) was consulted if a consensus could not be reached.

Data were extracted into Microsoft Excel (V.2307) using Cochrane's data extraction form and guidelines, including author, year, country, study type, sample size, mean age, gender ratio, income levels for each country, general climate information and diagnostic criteria for DED (clinical vs symptomatologic questionnaire diagnosis). Data were extracted by one reviewer and validated by another reviewer.

The risk of bias and quality of studies were assessed by YZ and DL using the Joanna Briggs Institute (JBI) critical appraisal checklist for observational studies.[17] Any disagreement was resolved by discussion with a third reviewer (VFC).

Data on the classification of countries by income level are from the official website of the World Bank.[18] General climatic information was obtained from the application ERA5 explorer of the Copernicus Climate Change Service.[19] Meteorological data prior to 2020 were plotted in map format, while data from 2020 to 2023 were exported directly from the database, using the closest latitude and longitude coordinates.

Data synthesis and analysis

In the absence of established diagnostic criteria or recommended procedures for diagnosing DED in children, two diagnostic models have been referenced. The first model is based on adult diagnostic criteria, including the Women's Health Study criteria,[20] which defines DED as a previous diagnosis of DED or the presence of severe symptoms, such as persistent or frequent dryness and irritation. This approach closely resembles the use of symptom-based questionnaires for diagnosing

DED. The second model incorporates criteria from the TFOS,[21] the Asian Dry Eye Association,[22] the Chinese Dry Eye Association[23] and the Japanese Dry Eye Association.[24] These criteria involve assessing both signs and symptoms of DED, though the specific diagnostic reference values differ across organisations. Based on these two diagnostic models, we divided paediatric DED into two groups. The first group consisted of studies that used validated questionnaires, originally designed for adults, to diagnose DED in children. The second group consisted of studies that used any validated clinical test to diagnose DED in children. These two groups were defined as (1) the questionnaire diagnosis group, in which DED was diagnosed on the basis of symptoms alone and (2) the clinical diagnosis group, in which DED was diagnosed by signs and symptoms.

Using Stata (V.18.0), we conducted a meta-analysis of the prevalence of DED among children. Proportions reported by the included studies were pooled using a random-effects model. The DerSimonian-Laird method was employed for pooling prevalence estimates, and results were presented as weighted averages of individual study proportions with their corresponding 95% CIs. Proportions were modelled directly, without logit transformation, given the goal of interpreting raw prevalence estimates in the paediatric population. The analysis was conducted separately based on study setting and diagnostic criteria for Clinical Setting with Clinical Diagnosis, Clinical Setting with Questionnaire Diagnosis, School/Community Setting with Clinical Diagnosis and School/Community setting with Questionnaire Diagnosis. A restricted maximum likelihood estimation was applied for subgroup analyses to compare settings such as clinical vs community-based studies. We performed subgroup analyses based on the following categories: study setting, diagnostic criteria, geographical area, temperature zone, country income level, study timing before or after the start of the COVID-19 pandemic. We used univariable meta-regression to investigate general climate information including latitude, annual average rainfall, annual average temperature and annual average humidity.

RESULTS

Study characteristics

The initial literature search identified 7309 articles. After removing 2911 duplicates, 4398 titles and abstracts were screened. After screening the titles and abstracts, 85 articles were retained and assessed for eligibility, among which 41 articles[24–64] were included in the review (figure 1). One article investigated the situation in both the Philippines and South Korea, which we reported separately, resulting in a total of 42 studies for meta-analysis. Donthineni *et al* found only 1023 cases of DED (0.4%) in a retrospective study of 259 969 children from 2010 to 2018 using electronic medical records.[65] The use of electronic records may reduce sensitivity, and more than 30% of the children were older than 18. Additionally, the study had a long observation period. Due to these limitations, it was excluded from the meta-analysis despite its large sample size. A list of excluded articles with reasons for exclusion is provided in online supplemental appendix 3.

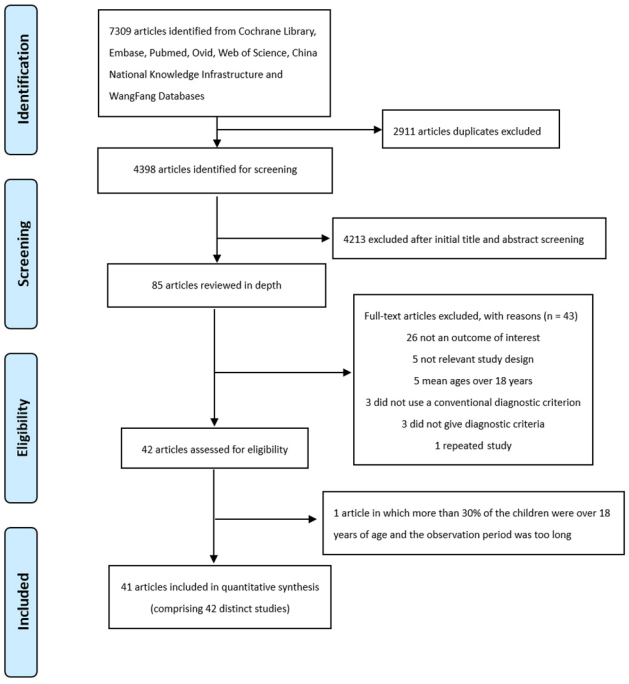

Figure 1 Flow diagram of literature search. Reported according to the Preferred Reporting Items for Systematic Review and Meta-Analysis guidelines.

All 42 studies included in the meta-analysis were cross-sectional and were conducted from 2008 to 2023. The studies included 48 479 participants (median 368; IQR 223–1926; range 60–5006) and were conducted in 14 countries, of which 35 studies (83.3%) were from Asia.[24–46 50 51 54 55 57–59 61–64] Four studies (9.5%) were from lower-middle-income countries (1 each from India,[41] Indonesia,[42] Egypt[60] and the Philippines[64]), 27 (62.3%) from upper-middle-income countries (1 each from Colombia[48] Mexico[53]and Thailand[62]) and 24 (58.5%) from China[25–40 45 46 51 54 57–59 63]) and 11 (26.2%) from high-income countries (1 each from New Zealand[47], the UK[49] and Saudi Arabia[61]; 2 from Japan[24 50] and the USA,[52 56] and 4 from South Korea[34 43 44 55]). 25 studies (59.5%) were conducted in a school or community setting,[26 28–30 32 35 36 38 40 42–44 46 48–51 53 55 57 58 62–64] while the rest (n=17,40.5%) in clinical settings.[25 27 31 33 34 37 39 41 45 47 52 54 56 59–61] 20 studies contained an approximately equal number of girls and boys,[24 26 28–30 32 35 36 38–41 43 45 51 53 57–59 63] 4 studies included <40% girls[31 33 44 50] and 1 study included <40% boys.[62] 17 studies did not report on the gender distribution of participants.[25 27 30 34 37 42 46–49 52 54–56 60 64] One study investigated the situation in both the Philippines and South Korea, which we reported separately.[64] The characteristics of the studies are described in online supplemental table 1.

Risk of bias and quality of included studies

The risk of bias and quality of the 42 studies are summarised in online supplemental figure 1. Observational studies were scored as low to moderate on the JBI Checklist for cross-sectional studies; common problems were (1) no CIs are given in the original (n=41)[24–62 64]; (2) lack of clear description of the study subjects and the setting (n=31)[25–31 33–35 37–45 49 50 52 54 55 57 59–61 63 64]; (3) lack of valid and reliable measurement of exposures (n=30)[24 26 28–35 37–44 48 54–58 61–64]; (4) inability to address potential confounding factors (n=9)[33 35 40 42 45 47 49 50 52] and (5) no confounding factors identified (n=4).[33 40 45 51] The working definitions to assess bias are presented in online supplemental table 2.

Prevalence of DED: primary meta-analyses

Figure 2 presents our primary meta-analysis involving sampling setting and diagnostic criteria. Among the 42 studies (48 479 participants), the pooled prevalence of DED was 23.7% (95% CI 18.5% to 28.9%; I^2=99.6%).

There was heterogeneity (p=0.01) among the four groups of studies formed by diagnostic criteria and setting. Lower values of DED prevalence were recorded in studies using clinical diagnosis as diagnostic criteria: 19.3% (95% CI 15.4% to 23.2%; I^2=86.1%; 11 studies; 2849 children) in clinical setting and 14.7% (95% CI 10.9% to 18.6%; I^2=98.8%; 15 studies; 24 258 children) in school/community setting. Studies using questionnaire to diagnose DED recorded higher prevalence estimates: 29.8% (95% CI 10.7% to 48.8%; I^2=99.6%; 6 studies; 2329 children) in clinical setting and 37.5% (95% CI 23.8% to 51.3%; I^2=99.8%; 9 studies; 19 043 children) in school/community setting. Heterogeneity was high in all groups formed by diagnostic criteria and setting, as expected in observational prevalence studies. Among studies using symptoms for DED diagnosis, there was a larger spread of prevalence estimates, with four studies finding values above 60%. Figure 2 shows how estimates obtained with questionnaires were highly variable for each questionnaire (Ocular Surface Disease Index (OSDI), Standard Patient Evaluation of Eye Dryness (SPEED), McMonnies, 5-item Dry Eye Questionnaire (DEQ-5)) except for four large studies using SPEED or Schaumberg questionnaires.

Online supplemental figure 2 presents a meta-analysis comprising 11 studies involving 2921 participants who wear contact lenses. The pooled prevalence of DED among these children is 42.6% (95% CI 27.0% to 58.1%, I^2=98.9%). Among studies focusing on DED in children who wear contact lenses, prevalence estimates varied widely. Four studies reported prevalence rates exceeding 70%, while two studies reported rates below 10%. The overall prevalence of DED, after excluding 2912 children who wear contact lenses, is 23.6% (95% CI 18.1% to 29.1%, I^2=99.7%), and this figure remained statistically unchanged (online supplemental figure 3).

Prevalence of DED: subgroup analyses

Table 1 shows the results of subgroup analyses by setting (online supplemental figure 4), diagnostic criteria (online supplemental figure 5), geographical area (online supplemental figure 6), temperature zone (online supplemental figure 7), country income (online supplemental figure 8) and effect of COVID-19 (online supplemental figure 9). In terms of setting subgroups, there are no statistically significant differences, the prevalence of school/community studies with better representation of the population being 24.1% (95% CI 16.8% to 31.5%; I^2= 99.8%; 25 studies; 43 301 children) and the prevalence of clinical studies being 23.1% (95% CI 15.9% to 30.4%; I^2= 97.8%; 17 studies; 5178 children). Diagnostic criteria subgroups were statistically significantly different (p<0.01 for subgroup heterogeneity), with clinical diagnosis yielding nearly half the DED prevalence compared with questionnaire diagnosis: 16.6% (95% CI 13.7% to 19.5%; I^2=98.0%; 26 studies; 27 107 children) and 34.6% (95% CI 23.7% to 45.6%; I^2=99.7%; 16 studies; 21 372 children), respectively. Prevalence was statistically significantly different before and after the start of the COVID-19 pandemic (subgroup heterogeneity p<0.01), where the prevalence of DED in studies before COVID-19 was 18.7% (95% CI 15.6% to 21.9%; I^2=98.7%; 34 studies; 39 316 children) and after the start of the pandemic the prevalence of DED increased to 44.1% (95% CI 25.5% to 62.7%; I^2=99.7%; 8 studies; 9163 children). Small differences in pooled estimates were apparent for other subgroups, but none were statistically significant.

Prevalence of DED: meta-regression on climate determinants

Table 2 shows the results of the meta-regression, including latitude (a proxy of temperature and sun irradiation), average annual rainfall, average annual temperature and average annual humidity for each study. In the univariable model, both latitude and average annual temperature were statistically significantly associated with DED, where DED prevalence increased by 7.1% for each 10° decrease in latitude (ie, moving towards the equator, p=0.015) and by 10.2% for each 10° mm increase in average annual temperate (p=0.010).

DISCUSSION

While DED has been widely recognised as a common eye disease in adults, it has been understudied in children.[15] The current study provides a comprehensive estimate of the global prevalence of DED in children and explores factors associated with DED. Our review identified no other studies reporting separately on the global prevalence of DED among children. We also observed an apparent increase in DED among children after the onset of the COVID-19 pandemic. Most notably, this review found that DED diagnosis by clinical signs versus by questionnaires of symptoms in children yield very different prevalence figures and require further study.

Our results suggest that the prevalence of DED among children is close to that in the adult population. The current study estimated the overall prevalence of DED in children to be 23.7%. A number of previous systematic

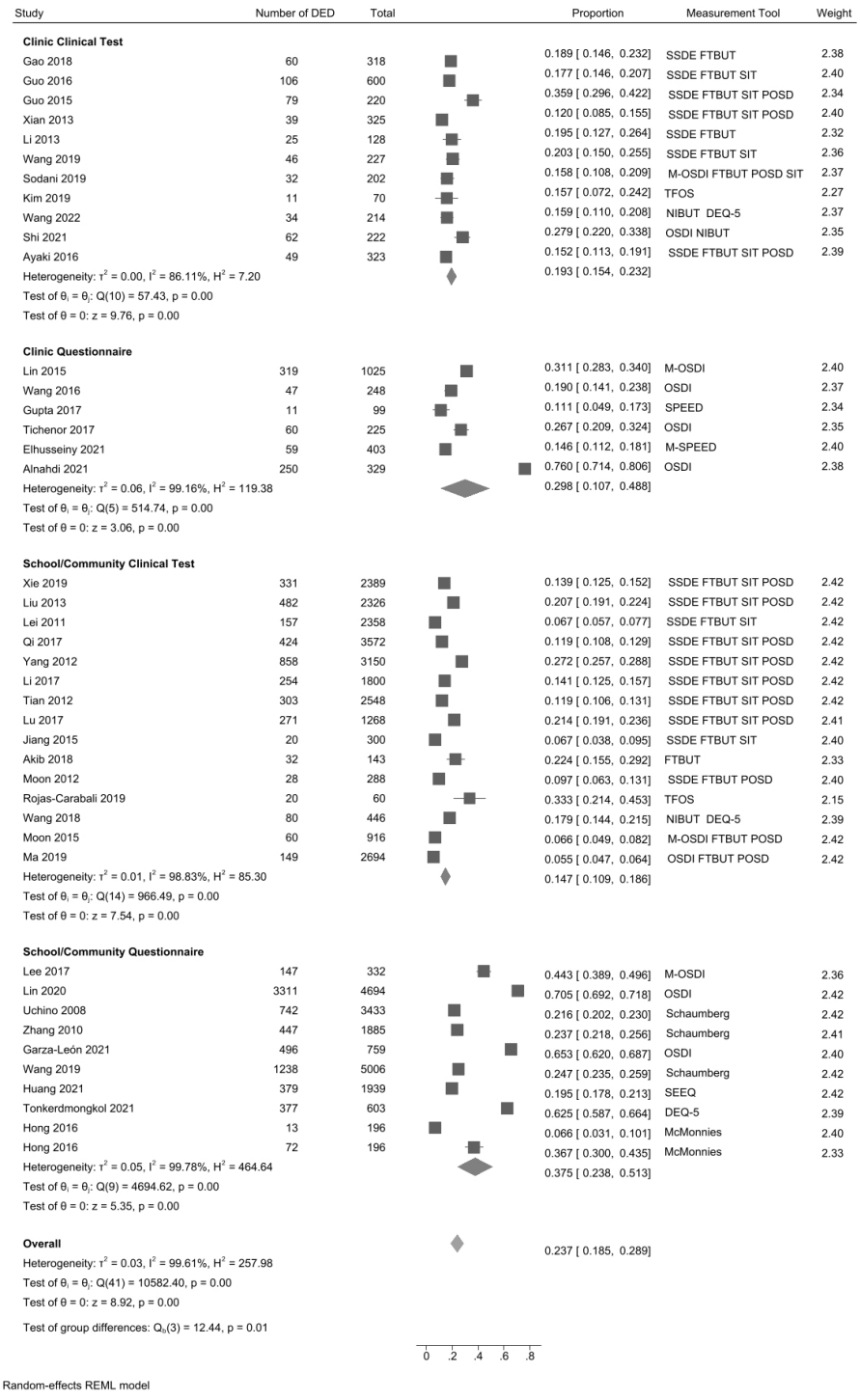

Figure 2 Forest plot of the prevalence of DED. DEQ-5, 5-item Dry Eye Questionnaire; FTBUT, Fluorescein tear break-up time; M-OSDI, Modify Ocular Surface Disease Index; M-SPEED, Modify Standard Patient Evaluation of Eye Dryness; NIBUT, Non-invasive tear film rupture time; POSD, positive ocular surface damage (fluorescein stain); SEEQ, Salisbury Eye Evaluation Questionnaire; SIT, Schirmer I test; SSDE, Subjective symptoms of dry eyes; TBUT, tear break-up time; TFOS, Tear Film and Ocular Surface Society.

reviews have reported DED estimates globally, and for Africa, Asia and the USA. The estimated prevalence of DED in Africa is 42.0% (95% CI 30.7% to 53.8%).[66] In relation to Asia, Cai *et al* included four studies reporting the prevalence of DED in people under 20 years old, and estimated that 11.9% of individuals suffer from DED (95% CI 4.4% to 19.4%).[67] A study in the USA reported that the population prevalence of DED was 8.1% (95% CI 4.9% to 13.1%), lower than seen in our study.[68] It is imperative to acknowledge the significant global burden posed by paediatric ocular surface health issues. Based on a median prevalence rate of 23.7% observed in school and community studies, an estimated 495 million children worldwide are affected by ocular surface disorders.

Table 1 Subgroup meta-analyses

Variable	Subgroups	n. studies (participants)	Estimate (95%confidence interval)	I^2	P value
Setting	Clinic	17 (5178)	23.1% (15.9–30.4)	97.8%	0.85
	School/Community	25 (43 301)	24.1% (16.8–31.5)	99.8%	
Diagnostic criteria	Clinical Diagnosis	26 (27 107)	16.6% (13.7–19.5)	98.0%	< 0.01
	Questionnaire Diagnosis	16 (21 372)	34.6% (23.7–45.6)	99.7%	
Geographic area	Asia	35 (46 417)	23.2% (17.5–28.9)	99.7%	0.68
	Non-Asia	7 (2062)	26.4% (12.2–40.6)	98.3%	
Temperature zone	Temperate	32 (40 393)	21.3% (16.2–26.5)	99.5%	0.18
	Tropical	10 (8086)	31.5% (17.4–45.7)	99.7%	
Country income	Lower-middle	4 (944)	22.1% (12.3–32.0)	92.3%	0.93
	Upper-middle	28 (41 203)	24.3% (17.9–30.7)	99.7%	
	High	10 (6332)	22.8% (10.6–35.1)	99.4%	
Effect of COVID-19	Before COVID-19	34 (39 316)	18.7% (15.6–21.9)	98.7%	0.01
	After COVID-19	8 (9163)	44.1% (25.5–62.7)	99.7%	

In line with the expected outcomes of observational epidemiological studies, the studies included in the analysis exhibited a high degree of heterogeneity. The wide variation in DED prevalence estimates reflects significant clinical and methodological heterogeneity across studies, including choice of clinical versus community or school-based cohorts. The studies included in our meta-analysis differed in population characteristics, study designs, general climate information and definitions of DED, all of which add to the uncertainty in overall prevalence estimates.

The prevalence of DED in our meta-analysis differed significantly between studies using clinical diagnosis versus questionnaire, 16.6% and 34.6%, respectively. Vehof *et al*'s study in adults found that dissociation of signs and symptoms of DED is an indicator of self-perceived health.[69] This finding suggests the possibility of a similar pattern existing among children. Higher prevalence of DED based on symptom-focused questionnaires in children is associated with more corneal nerve fibres and lower pain tolerance. Spierer *et al* showed that mechanical thresholds and pain thresholds correlate with age, resulting in children's susceptibility to detecting ocular surface discomfort.[70] Conversely, clinical test thresholds designed for adults may not be directly applicable to children. Healthy children typically exhibit a thinner lipid layer compared with adults.[71] Additionally, asymptomatic children may present with alterations in the appearance and function of their meibomian glands.[72]

The OSDI questionnaire, comprising 12 questions, includes inquiries such as whether vision problems have impacted nighttime driving (question 7) or computer usage or bank machine (question 8), which may pose challenges for children to answer. Chidi-Egboka *et al* found that 57% of children required adult supervision to complete the OSDI questionnaire, possibly due to difficulty understanding certain symptoms. This highlights children's lesser awareness of DED-related issues and terminology compared with adults.[64] Modifications to questionnaires, such as annotations or adjusted wording, may mitigate bias. Given the varying cognitive abilities of children, the questionnaire should include different versions for different age groups (0–4 years, 5–11 years and 12–17 years), with a parental proxy option for younger children who may have difficulty expressing symptoms.[73] For younger children (5–11 years) whose language skills are still developing, a simplified verbal and 3-point response scale with an expression scale ranging from happy to sad is used to help children understand the questions more easily.[74] Hence, tailored diagnostic tools and further research are necessary for paediatric DED diagnosis.

We found that the prevalence of DED was 18.7% before and 44.1% after the COVID-19 outbreak (p=0.01 for subgroup heterogeneity). Globally, governments implemented various control measures, such as restrictions on public activities, home quarantine, social distancing and school closures. Online schooling was used as an

Table 2 Meta-regression on climate determinants

Variable	Median (range)	Univariable	P value
Latitude (10° more)	35.69° (4.61, 51.5)	–0.071 (–0.139, –0.129)	0.015
Annual average rainfall (1000 mm more)	1022 (34–2997)	–0.027 (–0.130, 0.077)	0.615
Annual average temperature (10° more)	14°(0.9, 28)	0.102 (0.137, 0.190)	0.024
Annual average humidity (10% more)	69%(53, 83)	0.019 (–0.049, 0.087)	0.584

alternative to face-to-face teaching.[75] In line with other studies, Saldanha *et al* found an increase in the prevalence and severity of DED in adults following the COVID-19 outbreak.[76] Of the eight studies included in the analysis that were conducted after the COVID-19 outbreak, four studies[46 53 61 62] reported a high prevalence of DED. Three[46 53 61] used the OSDI questionnaire and one[62] used the DEQ-5 questionnaire. These studies involved high school students, potentially facilitating questionnaire comprehension. Conversely, the prevalence rates in the other four studies[54 58–60] closely aligned with the pre-COVID-19 average of 23.7%. The relationship between COVID-19 and DED may be influenced by various factors, necessitating further research to understand its effects on paediatric DED.

Contact lenses are recognised as an independent risk factor for DED in adults, but their impact on children remains inadequately characterised. Among the 11 included studies, only 3 used both signs and symptoms for diagnosis. Notably, two studies reported prevalence rates of less than 10%, while the prevalence of DED diagnosed using symptoms varied considerably. The relationship between DED and contact lens wear in children lacks definitive evidence. Given the rising prevalence of myopia and the increasing use of contact lenses to manage it among children, comprehensive multicentre studies are warranted to elucidate the association between DED and different types of contact lens use in this population.

This study reveals potential associations between climate factors and the prevalence of paediatric DED through a meta-regression analysis incorporating general climate information. We found increasing rates of DED with greater temperature and closer distance to the equator. Higher latitude results in a smaller angle of direct sunlight exposure, resulting in a lower impact on the ocular surface, likely yielding a lower prevalence rate.[77] Although the prevalence of DED increased with increasing temperature in our study, consistent results have not been obtained in several studies, and the relationship between temperature and DED requires further study.[78 79] Using more detailed environmental factors in a climate model (subtropical monsoon vs Mediterranean climate, etc), we may be able to better simulate the local effects of environment.[10]

This study highlights the urgent need to prioritise paediatric ocular surface health as a distinct clinical and public health concern. Traditionally underestimated, DED in children presents unique challenges, including the absence of standardised diagnostic criteria, which contributes to inconsistent prevalence estimates and hinders effective management. The paediatric ocular surface is anatomically and physiologically distinct from that of adults, rendering it more susceptible to environmental and behavioural influences such as increased screen time, contact lens use and extreme climates.

To improve detection and treatment, tailored diagnostic tools—such as simplified questionnaires and pediatric-specific clinical tests—are crucial. Clinicians must also account for environmental and lifestyle factors when evaluating children for DED, with a particular focus on high-risk groups. Future research should prioritise developing standardised diagnostic criteria and age-appropriate assessment tools for paediatric DED. Large-scale, multicentre studies are needed to investigate regional and environmental influences on prevalence and to clarify associations with emerging risk factors like digital device usage and climate. Longitudinal studies are also warranted to explore the long-term effects of paediatric DED on vision, mental health and educational outcomes. Through improved awareness, prevention strategies and targeted interventions, the growing burden of DED in children can be effectively addressed, ensuring better outcomes for this vulnerable population.

Strengths and limitations

This review has several strengths. First, we used a rigorous methodology and followed a predetermined, registered protocol. We developed a comprehensive search strategy that was not limited by language. In addition, we included studies with explicit diagnostic DED protocols in the meta-analysis, thereby reducing heterogeneity. Although this strategy may have excluded some well-designed studies, it enhanced the internal validity of the meta-analysis.

The results of the current review should also be interpreted given its limitations. Our analysis was limited to prevalence studies from only 14 countries, mainly in Asia, especially China. As a result, our findings may not be entirely representative of the global situation. There were no previous comparisons of DED prevalence among children in different regions. Due to the limited amount of prior research, we are currently unable to carry out a regional subgroup analysis. Second, despite strict criteria, significant study heterogeneity was observed. The high heterogeneity in the meta-analysis may be due to differences in population characteristics, study design, settings and diagnostic approaches for DED. In addition, some of the articles included in this study were of low quality with long study durations, which may have resulted in biased results. Our prevalence estimates do not incorporate prevalence in low-income economies, which may decrease generalisability of our study results. Stratification by gender was not possible due to insufficient sample size, and the relationship between gender and DED in children requires further study. Since most included studies did not differentiate between rural and urban settings, stratification on these variables was not possible. More studies with fully representative samples and common case definitions are needed to more accurately estimate the prevalence of DED among children.

CONCLUSIONS

This comprehensive meta-analysis demonstrates that DED is common in the paediatric population under the age of 18 years, which poses a serious burden to individuals and society. The prevalence and burden of

DED are likely to increase due to the widespread use of electronic screens and lifestyle changes resulting from COVID-19, which may affect children's mental health and educational attainment. Varying diagnostic criteria and inconsistencies in DED questionnaires for children have led to heterogeneity in its observed prevalence. The substantial variation in prevalence estimates reflects the need for standardised diagnostic criteria and age-appropriate diagnostic tools. Addressing paediatric DED will require a multidisciplinary approach that considers both clinical and environmental factors. Enhanced awareness and targeted interventions are critical for mitigating the growing burden of paediatric DED and safeguarding children's ocular and overall health.

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Funding This work was supported by the National Natural Science Foundation of China (82070928), and Huanhua Talent Program of Sichuan Provincial People's Hospital (SY2022023), and Chengdu Science and Technology Bureau (2022-YF05-01936-SN), and Sichuan Science and Technology Program (2021YJ0234, 2017YSKY0001-21).

Competing interests None declared.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. No data are available.

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