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Transmission of SARS-CoV-2 in educational settings in 2020: a review

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ABSTRACT

Objectives School closures have been used as a core non-pharmaceutical intervention (NPI) during the COVID-19 pandemic. This review aims at identifying SARS-CoV-2 transmission in educational settings during the first waves of the pandemic.

Methods This literature review assessed studies published between December 2019 and 1 April 2021 in Medline and Embase, which included studies that assessed educational settings from approximately January 2020 to January 2021. The inclusion criteria were based on the PCC framework (P-Population, C-Concept, C-Context). The study *Population* was restricted to people 1–17 years old (excluding neonatal transmission), the *Concept* was to assess child-to-child and child-to-adult transmission, while the *Context* was to assess specifically educational setting transmission.

Results Fifteen studies met inclusion criteria, ranging from daycare centres to high schools and summer camps, while eight studies assessed the re-opening of schools in the 2020–2021 school year. In principle, although there is sufficient evidence that children can both be infected by and transmit SARS-CoV-2 in school settings, the SAR remain relatively low—when NPI measures are implemented in parallel. Moreover, although the evidence was limited, there was an indication that younger children may have a lower SAR than adolescents.

Conclusions Transmission in educational settings in 2020 was minimal—when NPI measures were implemented in parallel. However, with an upsurge of cases related to variants of concern, continuous surveillance and assessment of the evidence is warranted to ensure the maximum protection of the health of students and the educational workforce, while also minimising the numerous negative impacts that school closures may have on children.

Strengths and limitations of this study

- This review followed a systematic search approach.
- The included studies of this review have heterogenous methodologies and a meta-analysis could not be performed.
- The search represents peer-reviewed literature that included previous SARS-CoV-2 variants but does not cover the Delta or Omicron variants.

INTRODUCTION

One of the more perplexing and controversial dimensions during the first year of the COVID-19 pandemic surrounded the role of children in SARS-CoV-2 transmission.

Epidemiological indicators of SARS-CoV-2 infection in children provide a complex picture regarding their potential role in the transmission chain. Systematic reviews have concluded that children and adolescents have lower susceptibility to SARS-CoV-2 infection.[1 2] However, when infected and symptomatic, children may shed viral RNA in similar quantities to adults,[3] and younger children (under 5 years) with mild-to-moderate symptoms may shed even more virus than older children and adults.[4] While the proportion of asymptomatic SARS-CoV-2 infections among children in the general population is uncertain, initial data had indicated that 16% of paediatric cases in Europe in the first phase of the pandemic were classified as asymptomatic,[5] while up to 90% of paediatric cases in China were deemed to be asymptomatic, mild or moderate.[6] Moreover, it is possible that children are less often asymptomatic carriers than adults: a study of non-COVID-19-related hospitalisations in Milan identified 1% of children and 9% of adults as asymptomatic carriers of SARS-CoV-2.[7] While children have been noted to have lower rates of severe COVID-19 cases,[8 9] there was during 2020 evidence of differing transmission dynamics between younger and older children.[2] T Index casesunder approximately 10 years of age were reported to lead to lower secondary attack rates (SAR) than older children and adults,[10 11] although more recently, due to a combination of differential vaccination coverage rates across age groups as well as circulation of the more transmissible Omicron variant of concern, it is unclear if such an association still holds.[12]

Important potential sources of evidence surrounding the role of children in the COVID-19 pandemic come from studies situated in the community, household, healthcare or educational settings. Transmission of SARS-COV-2 has thus far been documented to be higher in household settings than in other community settings—including schools—a finding which may be potentially attributable to the individual, behavioural and contextual factors of households versus other settings, as has been suggested elsewhere.[10]

Although at the time of writing the more transmissible Delta and Omicron variants are driving SARS-CoV-2 transmission, there is currently a gap in published studies looking at the transmission of COVID-19 during the first waves in school settings. However, as ensuring high levels of preparedness in school settings should remain a priority,[13] the literature published thus far may have important insights to guide decision-making around school closures and re-openings, as well support decision-making for mitigation measures in educational settings. With the above in mind, this literature review was conducted to assess child-to-child and child-to-adult SARS-CoV-2 transmission within educational settings during the first wave of the pandemic and to calculate where possible the SAR when the child is the index case.

METHODS

Search strategy

This literature review is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[14] Relevant studies published between December 2019 and 1 April 2021 were identified by searching Medline and Embase. The following set of inclusion criteria were used to determine eligibility of the studies, which is based on the PCC framework (P-Population, C-Concept, C-Context). The study *Population* was restricted to people aged 1–17 years (excluding neonatal transmission[15]), the *Concept* was to assess child-to-child and child-to-adult transmission when the child is the index case, while the *Context* was to assess specifically educational setting transmission clusters. Subject heading terms and free text words relating to the Population, Concept and Context terms as identified in the inclusion criteria were used to develop a comprehensive list of terms for the search strategy (so as to ensure we would not loose information), from which this specific review on educational settings was based. We included all studies of quantitative research, while, opinion pieces, commentaries, case reports and editorials were excluded. Mathematical modelling and simulation studies were also excluded. We additionally screened reference lists of the included articles to identify further relevant studies. The search was limited to the English language. The search terms of the review are presented in the online supplemental file.

Study selection

Initially, a pilot training screening process was used where 100 identical articles were screened for their eligibility independently by two reviewers to ensure consistency in screening. As a high measure of inter-rater agreement was achieved between the two reviewers during the pilot assessment (percentage agreement >90% and/or Cohen's kappa >0.81), the remaining titles were randomly allocated to the two reviewers and screened for eligibility independently by them. After an initial selection of the titles, each reviewer assessed each other's selected studies. The retrieved articles were then independently double-screened by two reviewers based on the full text of the articles.

Data extraction

The data extraction template was piloted independently by the two reviewers on a random sample of two included studies to enable an assessment of consistency in data extraction and to identify where amendments needed to be made to the template. The remaining studies were then data extracted independently by two reviewers, and the results were double-checked across the original manuscript by a third reviewer.

Data synthesis

Characteristics of the included studies were presented in tabulated form detailing the study design, geographical location of the study, sample size, characteristics of the populations considered, setting, context, parallel implemented non-pharmaceutical interventions (NPI) and the findings of the study. Depending on the level of information available, infection SAR were noted as defined in each included study. A narrative synthesis approach was applied to look systematically at the data and to describe each study categorised by the study design. Patterns in the data were identified through tabulation of results, and an inductive approach was taken to translate the data to identify areas of commonality between studies.

Patient and public involvement statement

Patients or the public were not involved in the design, or conduct, or reporting, or dissemination plans of our research.

RESULTS

Study selection and description

A total of 5406 studies were identified according to the specified selection criteria from Medline and Embase. After the removal of duplicates, 5233 were screened by title/abstract, out of which 333 were assessed via full text and 15 studies subsequently included in this review. The PRISMA flow chart showing the flow of study selection is presented in figure 1.

Fifteen published studies were identified to report child-to-child and/or child-to-adult transmission of SARS-CoV-2. Timeframes of data collection within these

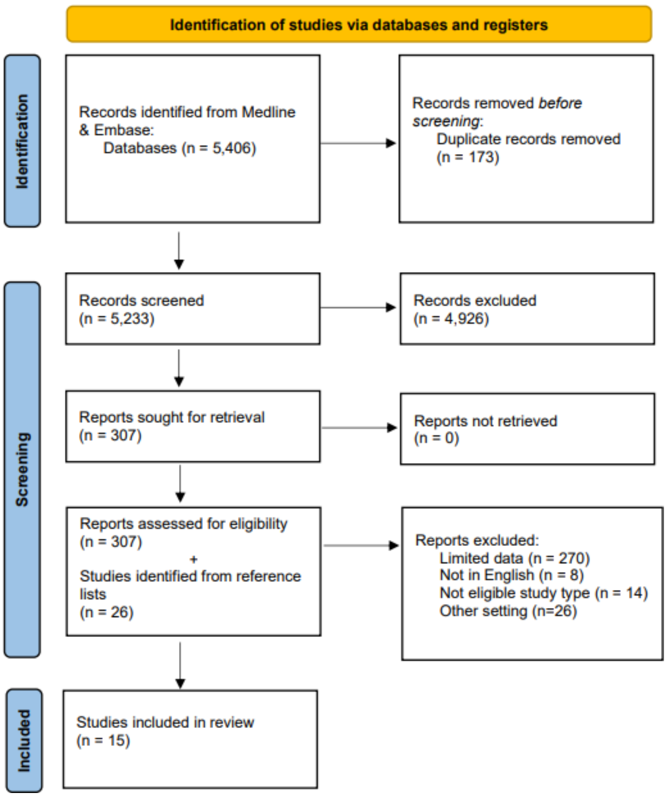

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analysis flow chart of study selection included in the rapid review.

studies ranged between January 2020 and January 2021. Studies from 11 countries were included (USA, South Korea, Israel, Germany, Italy, Ireland, France, Singapore, Australia, Norway and England). A full detailed overview of the published studies is provided in table 1.

Studies assessing outbreaks in educational settings

Heavey *et al*[16] conducted a case study in order to explore the role of transmission among children in the school setting in Ireland, before school closure. Three paediatric index cases of COVID-19 with a history of school attendance were detected with 895 contacts. Child-to-adult transmission or child-to-child transmission was not reported in this study. Similarly, Danis *et al*[17] presented the contact tracing results of a 9-year-old child in France, who visited three different schools the first days of symptom appearance. There was no evidence of secondary transmission in any of the school contacts. Moreover, Yung *et al* traced three COVID-19 cases (two paediatric and one adult) in three different educational settings, and the results were negative, as were the tracing of close contacts of a preschool case in South Korea.[18] Gold *et al* in early 2020 had also indicated the possibility of educators playing a role in school transmission as identified through the assessment of transmission clusters in primary (elementary) schools in Georgia, USA. More specific, in four clusters the index case was an educator, while a student was the index case in one cluster.[19] Lopez *et al* assessed three COVID-19 outbreaks in child care facilities in Utah, during 1 April–10 July 2020 and noted that SARS-CoV-2 infections among young children acquired in child care settings were transmitted to their household members.[20]

One study from New South Wales, Australia presented an overview of COVID-19 cases and transmission in schools. In a total number of 15 schools and 10 early childhood educational and care settings, 27 index cases were identified, among which 12 were children and 15 staff members. Secondary transmission was noted in only 4 of 25 educational settings.[21]

Studies assessing the re-opening of schools and summer camps

Eight studies reported on the regional evidence after the re-opening of schools. A school outbreak in Israel after re-opening of schools in May 2020 was described by Stein-Zamir *et al*. The outbreak assessment was initiated by two paediatric COVID-19 cases that were not epidemiologically related. The results showed that 153/1161 students and 25/151 staff members tested positive for COVID-19.[22] A study by Link-Gelles *et al*, in Rhode Island, USA, among 666 child care programmes revealed 52 confirmed and probable cases (33 confirmed cases), of which 30 were among children and 22 among adults. Secondary transmission for 10 cases was noted in only 4/666 childcare programmes.[23] The regional re-opening of schools in Germany in May 2020 was assessed by Ehrhardt *et al*, who noted that child-to-child transmission in schools/childcare facilities appeared very uncommon, with an estimated 6 of the identified 137 cases that had attended school to have led to a secondary transmission overall to 11 additional pupils.[24] While two additional studies from South Korea by Yoon *et al* indicated that on the return of children to school in May–June 2020, no indication of secondary transmission was noted in kindergarten children, middle school or high schools, while in primary school only two cases of secondary transmission was noted.[25 26] The re-opening of schools in September 2020 in Italy was not associated with elevated SAR, which reached 3.8% overall, 0% in preschool, 0.38% in primary and 6.46% in secondary schools, however these percentages included both adult and child cases.[27] Brandal *et al* assessed the transmission of COVID-19 in school settings in Norway between August and November 2020 and identified minimal child-to-child (0.9%, 2/234) and child-to-adult (1.7%, 1/58) transmission.[28]

Summer educational camps are presented separately, as close proximity between students is noted within school hours and throughout the day and night due to additional extra curricular activities and close sleeping proximities. Two studies assessed secondary transmission within summer educational camps, with striking differences. Pray *et al* identified a rapid transmission of SARS-CoV-2 at an overnight retreat where adolescents and young adults aged 14–24 years had prolonged contact and shared sleeping quarters, where one index case/child led to the infection of 76% of attendees.[29] On the contrary, Blaisdell *et al* in four overnight camps noted no

Table 1 Studies assessing SARS-CoV-2 transmission in educational settings, reported secondary cases and parallel non-pharmaceutical interventions, until January 2021

Study	Country	Timeframe	Age range*	Setting	No. of symptomatic paediatric index cases	No. of asymptomatic paediatric index cases	Secondary cases in the school settings†	Parallel non-pharmaceutical interventions in the community setting
Child care settings								
Lopez *et al*[20]	USA, Utah	April–July 2020	0.2–16	3 childcare facilities (3 clusters)	0 child (3 adults)		Transmission was documented from 12 secondary paediatric cases (3 asymptomatic) to at least 12/46 non-facility contacts (confirmed or probable cases)	Quarantine for 14 days of cases+contacts; in 2 facilities: daily screening and staff members were using masks.
Yoon *et al*[26]	South Korea	February–March 2020	4	1 childcare centre	1 (information about symptoms not reported)		0/190	Adult staff wore masks, but mask wearing by children were not consistent. After the index case-patient was identified, the centre was closed. All potentially exposed persons were quarantined at home for 14 days.
Combined childcare-school settings								
Heavey *et al*[16]	Ireland	March 2020	10–15	Schools	2	1	0/822 school contacts 0/73 other contacts	Exposure before school closure. Schools closed, contacts were quarantined.
Danis *et al*[17]	France	January to February 2020	9	3 schools	1	0	0/86 school contacts 1/6 hospitalised contacts	Not reported.
Yung *et al*[62]	Singapore	February to March 2020	2.8–15	3 schools	2	0	0/42 symptomatic contacts	Contacts were quarantined. Targeted measures at the school level.
Macartney *et al*[21]	Australia, New South Wales	25 January to 10 April 2020	<18	15 schools and 10 childcare settings (3 clusters)	12 (information about symptoms not reported)		3/752 (3: 2 children and 1 adult)	Contacts were quarantined.

Continued

Table 1 Continued

Study	Country	Timeframe	Age range*	Setting	No. of symptomatic paediatric index cases	No. of asymptomatic paediatric index cases	Secondary cases in the school settings†	Parallel non-pharmaceutical interventions in the community setting
Stein-Zamir *et al*[22]	Israel	May 2020	12–18	1 high school (1 cluster)	2	0	178/1312 (178: 153 children and 25 staff)	Closed spaces with poor ventilation, high temperatures, crowded spaces and close contact with no masks.
Link-Gelles *et al*[23]	USA, Rhode Island	June–July 2020	<18	666 educational settings (4 clusters)	33 confirmed and 19 probable cases in 29 settings		17 cases in 4/666 educational settings	Class distancing, the use of face masks for adults, universal symptom screening daily and disinfection.
Ehrhardt *et al*[24]	Germany, Baden-Württemberg	May–August 2020	<18	Schools and childcare facilities (11 clusters)	137 (information about symptoms not reported)		11/>2300, estimation of 1 secondary case per roughly 25 infectious school days	Masks, social distancing, hygiene, ventilation, smaller class sizes, cancelled activities, exclusion of sick children.
Brandal *et al*[28]	Norway, Oslo and Viken counties	August–November 2020	5–13	Primary schools (2 clusters)	13 (information about symptoms not reported)		3/292 (3: 2 children and 1 adult)	National guideline-based infection control measures, that is, hygiene, physical distancing, symptomatic children to stay at home. Masks not worn in schools.
Gold *et al*[19]	USA, Georgia	December 2020–January 2021	5–13	8 primary schools (9 clusters)	1 (information about symptoms not reported)		5/contacts traced not reported	Physical distancing and masks; imperfect compliance noted.
Larosa *et al*[27]	Italy, Reggio Emilia	September–October 2020	<18	8 preschools, 10 primary 18 secondary (9 clusters)	43	0	17/1198 (17 children and 0 adults)	Mandatory surgical masks for children except when seated and not speaking; physical distancing measures.
Yoon *et al*[25]	South Korea	Up to July 2020	<18	6 preschools 13 primary, 6 secondary, 14 high schools (2 clusters)	44 (information about symptoms not reported)		2/≥13 100	School closure continued until 6/4/2020. Social distancing strategies and mask wearing when schools opened with rigorous contact tracing and rapid testing on any suspected cases.
Summer camps								
Pray *et al*[29]	USA, Wisconsin	July–August 2020	14–24	1 overnight camp	1	0	115/151 confirmed or probable cases	Documentation of a negative pre-arrival RT-PCR result, 7-day pre-arrival quarantine and outdoor programming.

Continued

Table 1 Continued

Study	Country	Timeframe	Age range*	Setting	No. of symptomatic paediatric index cases	No. of asymptomatic paediatric index cases	Secondary cases in the school settings†	Parallel non-pharmaceutical interventions in the community setting
Blaisdell *et al*[30]	USA, Maine	June–August 2020	7–18	4 overnight camps	0	1	No secondary transmission identified	Pre-arrival quarantine, pre-arrival and post-arrival testing and symptom screening, cohorting, use of face coverings, physical distancing, enhanced hygiene measures, cleaning and disinfecting and maximal outdoor programming.

*Except when the age refers to only one paediatric case and age range is n/a.
†Measured from the date of last contact.
‡Probable cases.
n/a, not available.

indication of secondary transmission following the isolation of the paediatric index case and quarantine of their cohort, indicating the importance of the implementation of NPIs to reduce COVID-19 transmission.[30]

Secondary attack rates of COVID-19 transmission in educational settings

Table 2 presents the SAR extracted from the studies, ranging from 0% to 76%, depending on the setting, the timeframe and the implementation of NPIs. With the exception of the study by Pray *et al*,[29] within the context of summer camps in which a high transmission rate (76%) was noted, in all studies within the context of school settings, the reported SARs were minimal. Age differentiations were noted, for instance, in the study by Larosa *et al*, across 36 schools in northern Italy, who identified an overall SAR of 3.2%, reaching 6.6% in middle and high schools and 0.38% in primary schools.[27]

DISCUSSION

This study provides a rapid review of the peer-reviewed literature pertaining to SARS-CoV-2 transmission by children within educational settings, a topic which is a crucial input to assessments of the role of school settings in COVID-19 transmission. The literature appraised in this review provides sufficient evidence that children can both be infected by and transmit SARS-CoV-2 in school settings, however the reported SARs were often relatively low within the studies assessed by our review, reflecting-primarily SARS-CoV-2 transmission during 2020. Our results with regard to educational settings are in line with population-based studies published after the cut-off of this review, in which SARS-CoV-2 outbreaks were reported to be uncommon in educational settings[31] in England,[32] Canada[33] and in Utah, USA,[34] Missouri, USA,[35] New Jersey, USA[36] and North Carolina, USA[37] during similar periods.

During the first waves of the COVID-19 pandemic, the vast uncertainty surrounding the epidemiology of SARS-CoV-2 led many countries globally to include school closures concomitant with other NPIs for reducing COVID-19 transmission. Within our review, there were limited cases in the assessed studies in which a child index case was responsible for extensive secondary transmission in schools, with the notable exception of an outbreak in Israel (which was associated with dense spacing, lack of the use of facemasks and closed spaces with poor ventilation) and secondary transmission within summer educational camps, where prolonged exposure between case-contact pairs was likely.[29] The latter finding is supported by data from a large population-based study assessing transmission dynamics that identified that patterns of enhanced transmission risk in similar age pairs were strongest among children aged 0–14 years.[2]

Among studies that note a very small number of cases after school re-opening,[38 39] authors attribute this to the strict implementation of NPIs, including the use of

Table 2 Studies that assessed the secondary attack rate (SAR)*, when children are the index case within educational settings

Study	Country	Timeframe	SAR
Heavey *et al*[16]	Ireland	March 2020	0
Danis *et al*[17]	France	January–February 2020	School: 0/86, community: 0/80, hospitalised: 1/6
Yung *et al*[62]	Singapore	February–March 2020	0/42
Macartney *et al*[21]	Australia, New South Wales	25 January–9 April 2020	All settings, all child case to child contacts 0.3% (2/649) All settings, all child case to staff member contacts 1.0% (1/103), Child close contacts 28.0% (7/25)
Stein-Zamir *et al*[22]	Israel	May 2020	178/1312
Heavey *et al*[16]	USA, Rhode Island	1 June–31 July 2020	n/a
Pray *et al*[29]	USA, Wisconsin	July–August 2020	115/151 (76%)
Blaisdell *et al*[30]	USA, Maine	June–August 2020	0
Lopez *et al*[20]	USA, Utah	April–July 2020	n/a
Ehrhardt *et al*[24]	Germany, Baden-Württemberg	25 May–5 August 2020	Estimation of one secondary case per roughly 25 infectious school days
Brandal *et al*[28]	Norway, Oslo and Viken counties	28 August–11 November 2020	Child 2/234 (0.9%), adult 1/58 (1.7%)
Gold *et al*[19]	USA, Georgia	1 December 2020–22 January 2021	n/a
Larosa *et al*[27]	Italy	1 September–15 October 2020	38/994 (3.82%) overall 0.38% in primary schools (1/266) 6.46% in secondary schools (37/572)
Yoon *et al*[26]	South Korea	27 February–16 March 2020	0
Yoon *et al*[25]	Korea	Up to 31 July 2020	2/≥13 100

*The extracted SAR based on the original definition given by the authors in each study.
n/a, not available.

face masks, physical distancing, screening for symptoms and classroom disinfection.[23] Close proximity between students was linked to elevated transmission rates in both school settings and educational camps,[22 29] while adult educators have also been noted to play a role in school transmission.[19]

Modelling studies using various assumptions of SARS-CoV-2 infectivity from the first 3–4 months of the pandemic[40–46] have previously assessed the role of school closures and have indicated that school closures are associated with a reduction in the number of cases, hospitalisations and intensive care unit admissions, with the effect of school closure dependent on the transmission rate and the duration of school closure. Within this context, age is noted to be a crucial aspect, as modelling studies from the Netherlands indicated that contact restrictions within the age group of 10–20 years caused a slightly more significant reduction in Re, the effective reproduction number, compared with age group of 5–10 years.[47] Another European study that assessed school closure, based on the population of two large cities of Norway, Oslo and Tromsø, indicated that a controlled and gradual school re-opening would only have a slight increase in the reproduction number of <0.25, and probably in the range between 0.10 and 0.14, which would not substantially affect the infection rates.[48 55]

Modelling studies assessing school closures have challenges in disentangling the impacts of school closures from other related NPI measures, notably workplace closures and remote-work policies[49] . A rapid review conducted by Viner *et al*,[50] underlined that while modelling studies support the closure of educational institutions as part of the social distancing measures that need to be implemented, the only study examining school closures exclusively found relatively marginal impact, by reasonably assuming increased levels of household and community transmission as a result. However, a review that included only empirical studies, conducted by Mendez-Brito *et al*,[51] indicated that school closures, followed by workplace and entertainment venue closures and bans of public events, were the most effective NPIs, concluding that an early response and a combination of specific social distancing measures are of crucial importance for the reduction of COVID-19 cases and deaths.

While school closures may reduce SARS-CoV-2 transmission, the societal and economic impacts of prolonged school closure are noteworthy, as they may impact the availability of the healthcare workforce[42 52] and may also have negative effects on children through the interruption of the educational learning, social isolation, increased exposure to domestic violence and rise in dropout rates.[53] Furthermore, the impact of school closures has been noted to impact significantly also special education,[54] while research performed within the context of the COVID-19 pandemic has identified that contextual factors of particular relevance during school closures had negative impacts on student well-being.[55] In light of the above, policy makers need to be aware of the cost/benefit in each setting when considering school closures as a NPI.[50]

Transmission of SARS-COV-2 has been noted to be higher in household settings than other community settings, including schools, a finding which may be potentially attributable to the individual, behavioural and contextual factors of the household versus other settings, which may support transmission dynamics.[56] Direct evidence showing children as a source of transmission is scarce and largely based on small studies or studies investigating few paediatric cases, however the results presented here concur with other and previous systematic reviews that have summarised the evidence on the role of children in SARS-CoV-2 transmission.[47 57 58]

There are important limitations to this study that may impact the direct implications for decision-making. As we assessed peer-reviewed evidence published in two biomedical databases, it inherently reflects the status quo of the interim of the previous school years (January 2020–January 2021) due to the lag time between study implementation, peer review and publication. A further limitation of this report refers to the fact that these studies represent child-to-child transmission within the context of previous SARS-CoV-2 strains and are not directly applicable to newer and more transmissible variants, such as the SARS-CoV-2 Delta (B.1.617.2) variant of concern or the more recent Omicron variant. Finally, the included studies reflect a broad geographical and temporal range and are limited in comparability due to varying factors such as: background levels of community SARS-CoV-2 transmission; enrolment strategies and varying NPI policies which in turn depends highly on the geographical region and the socioeconomic context, while accountability to government and political stability were found to exert influence.[48] Hence in light of the above, supporting educators and parents in the implementation of NPIs is important as population-based studies have indicated that adults concerned about the impact of COVID-19 on their children's education were more likely to practice personal protective measures and social distancing.[59]

CONCLUSIONS

The findings presented here provide an assessment of the published peer-reviewed evidence on transmission in educational settings during 2020, in which transmission was minimal—when NPI measures were implemented in parallel. However, with an upsurge of cases related to new variants of concern, notably Delta and Omicron, continuous surveillance and assessment of the evidence is warranted to ensure the maximum protection of the health of students and the educational workforce, while also minimising the numerous negative impacts that school closures may have on children. Where or when schools remain open, in-school NPI measures should be continually refined according to new knowledge according to the epidemiological context, taking into account levels of community SARS-CoV-2 transmission, information on the severity of circulating SARS-CoV-2 variants, and vaccination coverage levels among eligible students, which includes children 5 and over in many jurisdictions.[60 61] Finally, future studies should focus more on identifying SARS-CoV-2 variants and on providing specific definitions about cases and contacts, while more detailed information on the contact tracing strategies and the implemented NPIs would reduce the limitations.

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