Health Information and Quality Authority

An tÚdarás Um Fhaisnéis agus Cáilíocht Sláinte

# Evidence summary of potential for children to contribute to transmission of SARS-CoV-2

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# Evidence summary of potential for children to contribute to transmission of SARS-CoV-2

## Key points

- Adults and children of any age can be infected with SARS-CoV-2 (the virus that causes COVID-19); however, to date reported cases of COVID-19 in children account for a small percentage of diagnosed cases. The role that children play in the transmission of the SARS-CoV-2 virus is unclear. This evidence summary includes studies on transmission of SARS-CoV-2 by children to others (child or adult) and does not address the risk of infection to children or their disease severity.
- In total, 13 studies were identified. Ten investigated intra-familial and close contact transmission, two examined transmission of SARS-CoV-2 in schools and one was a mathematical modelling study estimating age-specific transmissibility of SARS-CoV-2.
- Five of the 10 studies on intra-familial and close contact transmission reported child-to-adult or child-to-family member transmission, although at very low rates. There were concerns over the accuracy of the reporting in one of these five studies.
- Two studies assessed transmission within schools, with all individuals having an opportunity to transmit SARS-CoV-2 to others within their school:
    - An analysis of the spread of SARS-CoV-2 from six confirmed cases (three students and three staff) to 1,155 close contacts in Ireland (1,025 school contacts, 130 other settings) reported no confirmed transmission from children.
    - An analysis of the spread of SARS-CoV-2 from 18 confirmed cases (nine students and nine staff) to 863 close contacts (735 students and 128 staff) in 15 different schools in Australia reported one child from a primary school and one child from a high school may have contracted COVID-19 from the initial cases at their schools.
- The mathematical modelling study, estimating age-specific transmissibility of COVID-19, concluded that COVID-19 had high transmissibility among adults aged 25 years or older, but low transmissibility among children younger than 14 years.
- From the small number of studies identified, it appears that children are not, to date, substantially contributing to the household transmission of SARS-CoV-2.

From two studies, SARS-CoV-2 transmission in children in schools is also very low, however the evidence remains limited.

- Large scale studies focusing on transmission chains using data collected from contact tracing and serological studies looking for past evidence of infection are needed to determine how children are contributing to the spread of SARS-CoV-2.

## Introduction

The Health Information and Quality Authority (HIQA) has developed a series of 'Evidence Summaries' to assist the Clinical Expert Advisory Group (EAG) in supporting the National Public Health Emergency Team (NPHET) in their response to COVID-19. These summaries are based on specific research questions. This evidence summary was developed to address the following research question:

> **What evidence is available to indicate that children spread SARS-CoV-2?**

The processes as outlined in HIQA's protocol were followed (available at www.hiqa.ie). This summary was published in April 2020 and has been updated to reflect newly available evidence until 31 May 2020.

## Results

Eleven studies were included from the original search and previous updates (up to 21 May 2020). Two further studies were identified in this update, giving a total of 13 studies considered relevant for inclusion (Table 1). These comprised 10 studies of reported intra-familial and close contact transmission (nine primary studies[1-9] and one secondary analysis of data focused on household transmission clusters from published literature and publicly available data[10]); two reports on transmission of SARS-CoV-2 in schools settings;[11, 12] and a mathematical modelling study estimating age-specific transmissibility of SARS-CoV-2.[13] Six studies were from China,[1-3, 7, 8, 13] and one report each was from Ireland,[12] Switzerland,[9] Australia,[11] France,[4] Italy,[5] and Vietnam.[6] The secondary data analysis paper included data from China, Singapore, South Korea, Japan, and Iran.[10] Sample sizes for included child cases ranged from 1 to 74, and where reported, contact numbers ranged from 111 to 1,155.[2, 9, 11, 12]

### *Intra-familial and close contact transmission*

Ten studies (nine primary and one secondary analysis) examined intra-familial and close contact transmission. Of the nine primary studies, one was a case series of patients admitted to children's hospitals in China (n=10),[1] one was a case series

describing the epidemiological and clinical characteristics of 74 children with COVID-19 admitted to two hospitals,[3] one was a case series describing the dynamics of infection in the families of 39 children with COVID-19,[9] one was a cluster of COVID-19 cases in the French Alps,[4] three were case reports involving infants,[5, 6, 8] one a case report of an older child,[7] and one was an analysis of local heath commissions' public disclosures in China (n=419 index patients, 595 household secondary infections).[2]

The case series by Cai et al.[1] confirmed transmission of SARS-CoV-2 from one of the 10 included children to two family members. This transmission was from a three month old infant to both parents, who developed symptomatic COVID-19 seven days after taking care of the infant.[1] A case report of this infant confirms that, at the time of diagnosis, both parents had negative SARS-CoV-2 real time polymerase chain reaction (RT-PCR) results. Seven days after the child's hospitalisation, the father developed fever and fatigue, while the mother was asymptomatic; both parents showed signs of pneumonia on chest CT scan and had positive SARS-CoV-2 PCR results.[14] The secondary analysis of data study reported 31 SARS-CoV-2 household transmission clusters, of which 9.7% (3/31) were identified as having a paediatric index case.[10] The original papers for two of these cases could not be retrieved during this current review update, while the third case was of the infant described in the case series by Cai et al..[1] The authors conducted an analysis of the data assuming that asymptomatic children are being mistakenly overlooked as the index case in familial clusters. Using this approach (assuming asymptomatic children as the index case), 21% (6/28) of family clusters would have a paediatric index case.[10] A case series describing the dynamics of infection in the families of 39 children (<16 years old) with COVID-19 in Switzerland found a similar pattern, reporting that in 8% of cases (3/39) a child developed symptoms prior to any other household contact.[9] However, household contacts were asked to self-report whether they developed symptoms before, after or at the same time as the child case. The time to symptom onset or diagnosis was not reported with the authors noting that they could not confirm that child-to-adult transmission definitively occurred given the study design.

A case series describing the epidemiological and clinical characteristics of 74 children with COVID-19 admitted to two hospitals in China reported no evidence that the virus was transmitted from these 74 children to others, although there is limited reporting of how this information was ascertained in the manuscript.[3] Exposure data was available for 68 of the 74 patients with 65 (96%) of these cases being household contacts of adults whose symptoms developed earlier.

Danis et al.[4] investigated a cluster of COVID-19 cases in the French Alps, linked to one single adult index case. Eleven contacts of this index case tested positive for

SARS-CoV-2 (RT-PCR of upper or lower respiratory sample), of which one was a nine year old child, co-infected with other respiratory viruses (picornavirus and influenza A). While symptomatic, the child visited three schools (duration of visit was not reported) and attended one ski class. Overall, 172 contacts were identified of which 112 were school contacts. Of these, 169 individuals were contacted, 70 (41%) had respiratory symptoms during the investigation and a total of 73 were tested with one additional case of COVID-19 identified.

Three of the four case reports found no transmission of SARS-CoV-2. In an Italian case report, no transmission of SARS-CoV-2 from a COVID-19 positive 32-day-old boy to medical staff was documented.[5] Details on personal protective equipment and other precautions used by medical staff and transmission status to family members was not reported.[5] In a case report of a 3-month-old Vietnamese girl who acquired COVID-19 from her grandmother, the infant was isolated with her mother during hospitalisation.[6] The infant's mother was advised to wear a surgical face mask, practiced hand hygiene, and continued to breastfeed the infant. The mother remained negative for SARS-CoV-2 on repeated nasopharyngeal swabs.[6] In the case report of a critically ill infant in China,[8] it was assumed that the infant was infected during a hospital visit. The infant was cared for at home by his mother for 14 days post infection and neither of them wore a mask at home. Maternal RT-PCR and antibody tests were negative. Lin et al.[7] in a case report of a COVID-19 positive seven year old girl, conclude that the girl infected her father. However, the day before meeting his daughter, the father drove and took a bus to Xiangyang, Hubei province where he stayed overnight. Given this exposure to the epidemic area, coupled with inconsistencies of reporting of dates within the manuscript, it is also plausible that the father was the source of infection.

The analysis of public disclosures data[2] based on 419 index patients and their 595 household secondary infections, reported no cases of infection by an index patient 15 years of age or younger. Data presented suggests that three of the index patients were aged less than 18 years and were linked with three secondary cases; however, there are some concerns over the accuracy in the presentation of these data.

### *School-based transmission*

An analysis of Irish notifications of SARS-CoV-2 in the school setting found no transmission from children.[12] All notifications occurred in early March, before the universal school closure on 12 March 2020. Prior to this closure, when a case was identified within a school, either all children and staff within the school or all children and staff involved with an individual case were excluded, limiting the potential for further transmission. Three paediatric cases (all aged between 10 and 15 years) and three adult cases of COVID-19 with a history of school attendance were identified, along with 1,155 contacts (1,025 school contacts, 130 other settings). None of the

original six cases were infected with SARS-CoV-2 via the school setting. All cases except one had symptoms of either cough or fever. Contacts were exposed at school in the classroom, during sports lessons, music lessons and during choir practice for a religious ceremony, which involved a number of schools mixing in a church environment, although the length of time of these activities is not reported. The three paediatric cases had a total of 822 child contacts and 83 adult contacts within the school setting. No additional cases were identified during the follow-up period (14 days) from last contact with the index case. However, only contacts who developed symptoms were referred for testing, thus asymptomatic secondary cases were not captured. Transmission was observed in one instance outside the school environment, between two adult cases and a further adult.

A report released on 26 April from New South Wales, Australia examined transmission of SARS-CoV-2 in NSW schools.[11] It examined the spread of SARS-CoV-2 from 18 confirmed cases (nine students and nine staff) from 15 schools, to 863 close contacts (735 students and 128 staff) in these schools. A close contact was defined as a person who had been in face-to-face contact for at least 15 minutes or in the same room for two hours with a case while infectious. Close contacts of cases were usually either students or teachers who shared the same class or classes or extracurricular activities as the case or in their close circle of friends. All of these 18 cases are reported to have had an opportunity to transmit SARS-CoV-2 to others in their schools. The report's preliminary findings were that only two students may have contracted SARS-CoV-2 from the initial 18 cases. One secondary case (diagnosed based on the presence of antibodies) was presumed to have been infected following close contact with a student case in a high school. The other secondary case (nose/throat swab positive) was presumed to have been infected by a staff member (teacher), who was a positive case, in a primary school. A full peer-reviewed report is being prepared for publication.

### *Transmission modelling*

In a mathematical modelling study estimating age-specific transmissibility of SARS-CoV-2, Zhao et al.[13] concluded that SARS-CoV-2 had high transmissibility among adults aged 25 years or older, but low transmissibility among children or people younger than 14 years. The model fit was compared to data from 29 cases (10 of whom had exposure to the Huanan seafood market); this is a very small sample to check the fit of a model. Furthermore, those with exposure to the seafood market may not be representative of transmission patterns more generally.

## Study quality

The 11 primary studies reporting on transmission (nine primary intra-familial and close contact and two school-based) were of low to moderate quality for their design, as there was a lack of detail as to how cases were selected, what the criteria

for testing contacts was, what testing was undertaken and how consistently testing was conducted across all contacts.[1-9, 11, 12] Two studies had small sample sizes,[1, 4] four studies were case reports,[5-8] and three studies were pre-prints and had not undergone peer review at the time of writing.[2, 3, 11] Both studies in school settings had small numbers of child cases, but followed up large numbers of contacts.[11, 12] Symptomatic contacts were followed up for 14 days in the study by Heavey et al..[12] Length of follow-up was not consistently reported across other studies, and given potential transmission from asymptomatic contacts, the potential for missing cases cannot be ruled out. Two studies used existing public data,[2, 10] meaning there is potential for double counting of cases across studies. The secondary analysis of data focused on household transmission clusters from published literature and publicly available data was also a preprint.[10] The modelling study by Zhao et al.[13] had a very small sample to check the fit of a model and the sample from the seafood market may not be representative of transmission patterns more generally. This paper was also a pre-print, from a non peer-reviewed journal.

## Discussion

Adults and children of any age can be infected with SARS-CoV-2; however, to date reported cases of COVID-19 in paediatric populations account for a small percentage of all diagnosed cases. In a large national epidemiological study from Iceland (where 6% of the population underwent SARS-CoV-2 qRT-PCR testing), children under 10 years of age had a lower incidence of SARS-CoV-2 infection than adolescents or adults.[15] In the United States, the Centers for Disease Control and Prevention (CDC) has reported that less than 2% of COVID-19 cases reported by 2 April 2020, were in children under 18 years of age.[16] Data from Italy report that by 3 June, 2.1% of diagnosed cases were aged 18 or younger,[17] while in Spain 0.6% of 250,387 cases up to 21 May were aged less than 15 years.[18] Provisional data from the Health Protection Surveillance Centre demonstrate a similar pattern in Ireland with 2.0% of 25,373 confirmed cases, as of 19 June, aged less than 15 years.[19] However, paediatric SARS-CoV-2 is often milder than that in adults and a large proportion are likely to be asymptomatic.[20, 21] Given initial test capacity constraints, there has been an international trend towards restricting or prioritising RT-PCR testing to designated groups such as healthcare workers and or those with a greater disease burden. As a function of this, fewer cases may be diagnosed in children leading to a potentially higher relative underreporting. Emerging data from serological studies looking for evidence of past infection, also indicate that children have lower levels of previous infection. A Swiss population-based serosurvey for the period 6 April to 9 May 2020 measuring anti SARS-CoV-2 antibodies (the SEROCoV-POP study) estimated that in young children (aged 5–9 years), the risk of being seropositive was lower (RR 0.32 [0.11–0.63]) than in those aged 20–49 years the prevalence was also lower for the 10-19 year olds (RR 086

[0.57-1.22]); however this was not statistically significant.[22] Initial results from the Dutch PIENTER Corona study show that 1-2% of the under-20 age group have measurable antibodies against COVID-19 in their blood, compared to about 4% in adults.[23] However, is it not known if this lower prevalence reflects lower susceptibility to infection or lower exposure in the early stages of the pandemic due to social distancing measures. There are conflicting reports as to whether children are less susceptible to SARS-CoV-2 infection. A systematic review (pre-print published 24 May 2020) of 18 studies reported preliminary evidence that children and young people have lower susceptibility to SARS-CoV-2, with a 56% lower odds of being an infected contact within studies of contact-tracing.[24] A mathematical model study using data from six countries estimated that susceptibility to infection in individuals under 20 years of age was approximately half that of adults aged over 20 years.[25] They argued that low case rates in children could also be explained by age-specific severity, (that is, children are more likely to be asymptomatic and experience milder symptoms).[25] As possible confirmation of this trend, provisional results from the UK Office of National Statistics' based on home, self-sampling of nasopharyngeal swabs of over 10,000 individuals, found no evidence of differences between age groups in the proportions of those testing positive in the community (excluding infections reported in hospitals, care homes or other institutional settings). This would suggest that symptomatic children are as likely to test positive as other age groups.[26]

## *Reported transmission*

The WHO-China Joint Mission noted that infected children tended to be identified by contact tracing and that interviewees could not recall episodes of transmission from a child to an adult.[27] The emerging evidence in the included studies has highlighted child to adult or family member transmission has the potential to occur, although at extremely low rates. It is difficult to ascertain from the broader literature who exactly was the index patient. The largest case series of 74 children with COVID-19 reported no evidence that the virus was transmitted from children to others. However, four of the nine studies focused on intra-familial and close contact transmission suggested transmission from children to other family members could occur. There are concerns regarding two of these studies[1, 7] due to lack of information and inconsistencies of reporting within the manuscripts, it is also feasible that the virus could have been transmitted from the parents to the children. In their secondary analysis of existing data, Zhu et al.[10] reported that assuming asymptomatic children were the index case in all familial clusters would still produce a situation where children only accounted for a limited percentage of household cluster transmissions. Current studies, which have largely been conducted in the context of strict social distancing policies, indicate that children are mostly infected by family members in the home.[28-32] An analysis of 693 infector and infectee pairs

from recent data on reported cases from the Dutch National Institute for Public Health and the Environment (RIVM) highlights that COVID-19 is primarily spread between persons of approximately the same age and that most of these are between the ages of 40 and 80 years.[23] The data shows that it is less common for adults to infect children, but when this does happen, it mainly occurs in the home situation.

Of the two studies on transmission of SARS-CoV-2 in schools, one reported transmission occurred within schools. An analysis of Irish notifications of SARS-CoV-2 in the school setting before school closures on 12 March 2020 identified no paediatric transmission.[12] However, while contacts were followed for 14 days from exposure, only those who developed symptoms were referred for testing, so asymptomatic secondary cases were not captured. Preliminary analysis of data on the spread of SARS-CoV-2 within schools in New South Wales, Australia has demonstrated a low transmission rate. From 18 cases, there were only two confirmed transmissions out of 863 close contacts with only one case presumed to be transmitted by a child.[11] A rapid systematic review (published 1 May 2020) on school closure during coronavirus outbreaks (including COVID-19) found limited and conflicting information.[33] The authors cite recent modelling studies of COVID-19 which predict that school closures alone would prevent 2% to 4% of deaths, much less than other social distancing interventions.[33]

The mathematical modelling study also concluded that COVID-19 has low transmissibility among children aged less than 14 years. Some studies of familial transmission which describe presumed contact and transmission have not been included here. For example, in an analysis of open access databases, Henry et al.[34] reported that 35% (29 patients) of children and adolescents across 14 countries were noted to have an infected family member. However, they did not specifically report transmission from child to adult. Liao et al.[35] reported three cases where asymptomatic adolescents and young adults (aged 10 to 35 years) infected family members; however, it is unclear what age these patients were, so they have not been included in this review.

The majority of included studies have looked at familial transmission in known cases and it is often unclear in the literature who the index patient is. Only one study has examined transmission of SARS-CoV-2 in schools. These results are consistent with a recent review of literature and media reports of settings linked to SARS-CoV-2 transmission clusters which found most available reports came from households and with an increasing number reported in hospitals and elderly care settings across Europe. Very few transmission clusters were linked to schools.[36] This is perhaps unsurprising as analysis of social contact and age-mixing patterns in China during the outbreak period, where strict social distancing policies were in place, highlights

that typical features of age-mixing (school contacts, workplace contacts etc.) decreased and contacts during the outbreak mostly occurred at home with household members.[37, 38] Similar patterns would be expected in other countries where adherence to strict social distancing policies is achieved.

## *Transmission potential*

Although studies of real-life transmission remain limited, transmission potential of SARS-CoV-2 by children is influenced by a number of factors other than susceptibility to infection including potential for exposure to the virus and viral load (the amount of virus that a child might carry). In relation to exposure to the virus outside of the home, two recent pre-print studies looking for evidence of infection in childcare and school settings were identified (described in more detail in Table 2). While these studies do not present evidence on actual transmission chains from infected children to others, they do characterise the burden of COVID-19 within these settings during the epidemic period. Following confirmation of a COVID-19 patient in Oise, France, case investigation and contact tracing identified two cases in a high school (unclear if these were students or staff) who had symptoms consistent with COVID-19, although how they acquired SARS-CoV-2 was not determined.[39] As a follow-up to this initial case investigation, a retrospective study was conducted in the high school where participants, including high school pupils, teachers, non-teaching staff, parents, and siblings were invited to have their blood tested for the presence of anti-SARS-CoV-2 antibodies. Overall, 171 of the 661 participants (25.9%) had anti-SARS-CoV-2 antibodies.[39] Ninety-two of 240 (38.3%) high school pupils and 23 of 53 (43.4%) teachers had anti-SARS-CoV-2 antibodies, highlighting no substantial difference in infection between the two groups. Within the families of pupils, 24 of 211 parents (11.4%) and 13 of 127 siblings (10.2%), had anti-SARS-CoV-2 antibodies.[39] The number of new cases decreased around the beginning of the school holidays, and again after local confinement measures were introduced.[39] This study had a 37% response rate and it is unclear how the sample may have differed from the total high school population. This may have led to either an overestimation or an underestimation of the true burden. Furthermore, as there is no detailed information on transmission chains, how individuals acquired SARS-CoV-2 cannot be determined. In contrast, a study in Belgian day care settings reported no SARS-CoV-2 in a random sample of 84 children aged between 6 and 30 months, shortly after the start of the epidemic and before lockdown commenced.[40] This study was part of an on-going study of pneumococcal serotypes in children attending daycare centres. Nasopharyngeal swabs were taken from a random sample of 84 children attending eight different daycare centres (2-12 March 2020). While cold symptoms were common, all analysed samples were negative for SARS-CoV-2 based on real-time PCR test.[40]

We have conducted a separate review of viral load and infectivity over course of infection. A limited number of studies have been published to-date comparing viral loads between and adult and paediatric populations. While no discernible differences with regards to viral load or duration of virus detection between adults and children were reported, there are concerns regarding the statistical analysis undertaken in some of the included studies.[41] The relationship between viral load and infectivity is not well understood as viral load is only a proxy measurement of infectivity and may not translate to transmissibility. The HIQA review found evidence of prolonged viral shedding in stool samples, particularly in children. While potentially a source of faecal-oral transmission, the clinical significance of this finding is uncertain.[41] Separately, an investigation on environmental contamination in an isolation room of an infected infant was identified that reported that a generally well infant with COVID-19 can contaminate the environment with PCR-detectable virus.[42] However, reliable, large scale data on transmission from symptomatic and asymptomatic children is lacking.

### *Future research*

Large scale studies focusing on transmission chains using data collected from contact tracing and case investigations are needed to determine how children are contributing to the spread of SARS-CoV-2. As schools and childcare facilities gradually re-open internationally, more data on transmission chains linked to children outside of the household setting may become available. Serological studies looking for past evidence of infection, and studies assessing viral load in infected children and the relationship between viral load and transmission may also be helpful in understanding the role children play in transmission.[43]

## Conclusion

There is currently limited information on the contribution of children to the transmission of SARS-CoV-2. Very few definitive cases of virus transmission from children have been published to date. From the small number of published studies identified, it appears that children are not, to date, substantially contributing to the household transmission of SARS-CoV-2. From two school-based studies investigating transmission of SARS-CoV-2 in children, it appears that rates in this setting are also very low.

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## Table 1 Characteristics of included studies

| Author<br>Country<br>Study design | Population setting<br>Patient demographics<br>Clinical characteristics | Primary outcome results |
|---|---|---|
| **Cai**[1]<br><br>**China (Shanghai)**<br><br>**Case Series**<br><br>**DOI:** 10.1093/cid/ciaa198 | **Population setting:** 10 patients admitted to a Children's Hospital for screening based on presenting with acute fever and/or respiratory symptoms AND an epidemiological link to an adult case/exposure to an epidemic area.<br>**Demographics:**<br>*Age:* 3-131 months (mean: 74 months)<br>*Gender:* Male n = 4, female n = 6<br>**Clinical characteristics:**<br>*Presentation:* Fever n=8 (80%); cough n=6 (60%); sore throat n=4 (40%); stuffy nose n=3 (30%); sneezing and rhinorrhoea n=2 (20%).<br>RNA positive within 4-48 hours after symptom onset. RNA (nasopharyngeal/throat swabs) undetectable within 6-22 days (mean: 12 days) after illness onset.<br>RNA (faecal samples) positive 3-13 days after illness onset in five patients, and within 18-30 days after illness onset.<br>All patients discharged when they recovered with two consecutive RNA (respiratory samples) tested negative. | **Confirmed transmission**<br>Transmission from infected child to adult contacts: N=2<br>3-month-old infant whose 2 parents developed symptomatic COVID-19 7 days after looking after the infant. Source of infant infection not reported. Infant had positive nasopharyngeal swabs for 8 days.<br><br>Number of secondary symptomatic cases including the child and his/her family members who were exposed to a common index case and developed symptoms: 1 to 4 (mean: 2.43).<br><br>**Mean time to transmission/symptoms onset**<br>Not reported.<br>Parents developed symptomatic COVID-19 7 days after looking after the infant. |
| **Canarutto**[5]<br><br>**Italy**<br><br>**Case report**<br><br>**DOI:**<br>https://doi.org/10.1002/ppul.24754 | **Population setting:** 1 patient admitted to a Children's Hospital<br><br>**Demographics:**<br>*Age:* 32 days<br>*Gender:* Male<br><br>**Clinical characteristics:**<br>*Presentation:* low grade fever, rhinitis and cough (1 day history).<br>RNA positive nasopharyngeal swabs. | **Confirmed transmission**<br>Transmission from infected child to adult contacts: N=0<br>No transmission of the virus to medical staff was documented.<br>Transmission status to family members not reported.<br><br>**Mean time to transmission/symptoms onset**<br>Not applicable |
| **Danis**[4]<br><br>**France** | **Population setting:** 1 adult index case (laboratory-confirmed), 11 secondary cases and 1 tertiary case. | **Confirmed transmission**<br>Transmission from infected child: N=0 |

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| **Case Series (cluster)**<br><br>**DOI:** 10.1093/cid/ciaa424 | 1 paediatric secondary case (laboratory-confirmed) and 112 school contacts.<br>In total, 172 contacts (112 school-based) and 73 had RT-PCR tests.<br><br>**Demographics (paediatric case):**<br>*Age:* 9 years<br>*Gender:* Male<br><br>**Clinical characteristics (paediatric case):**<br>*Presentation:* symptomatic (unspecified) | **Mean time to transmission/symptoms onset**<br>Not applicable<br><br>**Other relevant findings**<br>Possible transmission of other viruses (picornavirus) by paediatric case: 3/10 (30%) of contacts |
| **Heavy[12]**<br><br>**Ireland**<br><br>**Epidemiological study**<br><br>**DOI: https://doi.org/10.2807/1560-7917.ES.2020.25.21.2000903** | **Population setting:** 6 COVID-19 cases (3 paediatric and 3 adult) with a history of school attendance and 1,155 contacts (1,025 school contacts, 130 other settings)<br>*Paediatric cases:* 1 primary school, 2 secondary school<br>*Adult cases:* 1 teacher, 2 adults providing educational sessions in schools for up to 2 hours.<br><br>**Demographics (paediatric cases):**<br>*Age:*<br>10-15 years: 3<br>*Gender:* Not reported<br><br>**Clinical characteristics (paediatric cases):**<br>*Presentation:* Fever 2, asymptomatic 1 | **Confirmed transmission**<br>Transmission from infected child: N=0<br><br>**Mean time to transmission/symptoms onset**<br>Not applicable. |
| **Le[6]**<br><br>**Vietnam**<br><br>**Case report**<br><br>**DOI:** https://doi.org/10.1016/S2352-4642(20)30091-2 | **Population setting:** 1 patient admitted to a Children's Hospital<br><br>**Demographics:**<br>*Age:* 3 months<br>*Gender:* Female<br><br>**Clinical characteristics:**<br>*Presentation:* rhinorrhoea, nasal congestion, fever.<br>RNA positive nasopharyngeal swabs. | **Confirmed transmission**<br>Transmission from infected child to adult contacts: N=0<br><br>At hospitalisation (day 6 after symptom onset) the infant was isolated with her mother. The infant's mother was advised to wear a surgical face mask, practiced hand hygiene, and continued to breastfeed the infant. Maternal repeated nasopharyngeal swabs were negative for SARS-CoV-2. |

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| | | **Mean time to transmission/symptoms onset**<br>Not applicable |
| **Lin[7]**<br><br>**China (Chongqing)**<br><br>**Case Report**<br><br>**DOI:**<br>https://doi.org/10.1002/ppul.24763 | **Population setting:** 1 patient admitted to a quarantine ward in a local country hospital<br><br>**Demographics:**<br>*Age:* 7 years<br>*Gender:* Female<br><br>**Clinical characteristics:**<br>*Presentation:*<br>Complaint of nasal obstruction for 2 days without cough, fever, dyspnoea or diarrhoea.<br>RNA positive throat swabs. | **Confirmed transmission**<br>Possible transmission from infected child to adult contacts: N=1<br><br>On 21 Jan 2020 the girl's father drove and then took a bus to Xiangyang, Hubei province where he stayed overnight but did not have close contact with anybody except family members. On 22 Jan 2020, the father self - drove from Xiangyang, Hubei to Chongqing city with the girl, her grandparents, mother, and 2 - year - old brother, arriving in the early morning of 23 Jan.<br><br>**Mean time to transmission/symptoms onset**<br>Girl's father presented with symptoms 5 days after meeting his daughter. |
| **National Centre for Immunisation Research and Surveillance (NCIRS)[11]**<br><br>**Australia (New South Wales)**<br><br>**Epidemiological study**<br><br>**URL:**<br>http://ncirs.org.au/sites/default/files/2020-04/NCIRS%20NSW%20Schools%20COVID_Summary_FINAL%20public_26%20April%202020.pdf | **Population setting:** 18 COVID-19 cases (9 students, 9 staff) and 863 (735 students, 128 staff) close contacts from 15 schools (10 high schools, 5 primary schools).<br><br>*High schools*<br>12 index cases (8 students, 4 staff) with 695 close contacts (598 students, 97 staff).<br>*Primary schools*<br>6 index cases (1 student, 5 staff) with 168 close contacts (137 students, 31 staff).<br>**Demographics:**<br>*Age:* Not reported<br>*Gender:* Not reported<br><br>**Clinical characteristics:**<br>Not reported | **Confirmed transmission**<br>Number of secondary cases in students: N=2<br>Presumed student to student transmission: N= 1 (high school), secondary case diagnosed based on presence of antibodies.<br>Presumed teacher to student transmission: N= 1 (primary school), secondary case diagnosed as nose/throat swab positive.<br>Presumed student to teacher transmission: N= 0<br><br>**Mean time to transmission/symptoms onset**<br>Not reported |

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| **Posfay-Barbe[9]**<br><br>**Switzerland**<br><br>**Case series**<br><br>**DOI: https://doi.org/10.1542/peds.2020-1576** | **Population setting:** 39 patients <16 years old with SARS-CoV-2 infection (7 inpatients, 32 outpatients) and 111 household contacts<br><br>**Demographics:**<br>*Median age (IQR):* 11.1 years (5.7 – 14.5)<br>*Gender:* Male n = 17 (44%), female n = 22 (56%)<br><br>**Clinical characteristics:**<br>*Presentation:* cough 32 (82%); fever 26 (67%); nasal discharge 25 (64%); headache 22 (56%); sore throat 14 (36%); shortness of breath 13 (33%); myalgia 13 (13%); abdominal pain 11 (28%); anosmia 8 (21%); arthralgia 7 (18%); diarrhoea 7 (18%); fatigue 5 (13%); rash 5 (13%); dysgeusia 4 (10%); nausea 4 (10%); vomiting 3 (8%); thoracic pain 2 (5%); conjunctivitis 1 (3%) | **Confirmed transmission**<br>Possible transmission: Cluster with a child developing symptoms prior to any other household contacts: N=3/39 (8%)<br><br>Number of secondary cases: 4 (3 mothers and 1 father)<br><br>**Mean time to transmission/symptoms onset**<br>Not reported |
| **Qiu[8]**<br><br>**China**<br><br>**Case report**<br><br>**DOI:** 10.1097/INF.0000000000002720 | **Population setting:** 1 patient admitted to a Children's Hospital<br><br>**Demographics:**<br>*Age:* 8 months<br>*Gender:* Male<br><br>**Clinical characteristics:**<br>*Presentation:* poor growth, malnutrition, cough<br>RNA positive nasopharyngeal and rectal swabs. | **Confirmed transmission**<br>Transmission from infected child to adult contacts: N=0<br><br>**Mean time to transmission/symptoms onset**<br>Not applicable |
| **Wu[3]**<br><br>**China**<br><br>**Case series**<br><br>**DOI:**<br>10.1101/2020.03.19.20027078 | **Population setting:** 74 paediatric laboratory-confirmed SARS-CoV-2 cases admitted in Qingdao Women's and Children's Hospital and Wuhan Children's Hospital<br>**Demographics:**<br>*Age:*<br>≤ 3 months: 7 (9.5%)<br>3 to 6 months: 4 (5.4%)<br>6 months to 1 year: 5 (6.76%)<br>1 to 3 years: 12 (16.2%)<br>3 to 10 years: 31 (41.9%)<br>>10 years: 15 (20.3%)<br>*Gender:* Male n = 44 (59.5%), female n = 30 (40.5%)<br><br>**Clinical characteristics:** | **Confirmed transmission**<br>Transmission from infected child to contacts: N=0<br><br>**Mean time to transmission/symptoms onset**<br>Not applicable |

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| | *Presentation:* Cough n=24 (32.4%); fever n=20 (27%); fatigue n=5 (6.8%); chest congestion n=4 (5.4%); anorexia n=3 (4%); diarrhoea (n=3 (4%); dyspnoea n=2 (2.7%); headache n=2 (2.7%), expectoration, n= 2 (2.7%)<br>*Severity of infection:* severe pneumonia n=1; mild pneumonia n= 29; acute upper respiratory tract infection n= 24; asymptomatic infection n= 20<br><br>RNA positive after symptom onset: Median 2 days (range, 1-6)<br>RNA (faecal samples) positive: 10/74 (13.51%)<br>Viral RNA remained positive in stools of 8 convalescent patients after respiratory specimens were negative, for a median of 11 days (range 5 to 23) | |
| **Xu[2]**<br><br>**China**<br><br>**Epidemiological study**<br><br>**DOI:** 10.1101/2020.03.02.20029868 | **Population:** 419 index patients and their 595 household secondary infections.<br>Index patient: first case patient and the only person who returned home from Wuhan/other cities in Hubei Province in the household.<br>Secondary cases: patients who had no known exposure to virus sources outside of the family.<br><br>**Setting:** Local Heath Commissions' public disclosures<br>**Demographics**:<br>Not reported<br>**Clinical characteristics:**<br>Not reported | **Confirmed transmission**<br>No case infected by index patient (first case patient) 15 years of age or younger was reported.<br><br>3 index patients were aged <18 years and infected 3 secondary cases, one aged 0-17 years, one 18-49 years and one 65+<br><br>**Mean time to transmission/symptoms onset**<br>No data on child transmission specified.<br>In the full data set, the time between the onset of symptoms in a case patient and the onset of symptoms in the household contacts infected by that patient, was 5.9 days. |
| **Zhao[13]**<br><br>**China (Wuhan City)**<br><br>**Mathematical model**<br><br>**DOI:** 10.1101/2020.03.05.20031849 | **Population data:** 29 COVID-19 cases, 10 with history of exposure to Huanan seafood market, 19 without exposure<br><br>**Model parameters data sources**<br>• Age group proportions, birth rate and death rate - Wuhan Statistical Yearbook<br>• Other parameters – literature | **Model with four-age-groups:**<br>Highest transmissibility occurred between the age groups 15 – 44 years and 45 – 64 years, among those ≥ 65 years, or from 45 – 64 years to ≥ 65 years.<br>Lowest transmissibility occurred from age group 0-14 years to 15 – 44 years, or from 45 – 64 years to ≤14 years.<br><br>**Model with five-age-groups:** |

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| | | Highest transmissibility occurred between age group 25 – 59 years and ≥ 60 years, or among 25 – 59 years.<br>Lowest transmissibility occurred from age group 15 – 24 years to 25 – 59 years, or from age group 0-5 years to 6-14 years, or, to 15-24 years. |
| **Zhu[10]**<br><br>**Five countries (China, Singapore, South Korea, Japan, and Iran)**<br><br>**Secondary data analysis of published data**<br><br>**DOI:** 10.1101/2020.03.26.20044826 | **Population:** 31 household transmission clusters, 94 cases, including 20 paediatric SARS-CoV-2 cases<br><br>**Setting:** review of published literature and datasets between December 2019 and March 2020<br><br>**Demographics of included children household transmission clusters (n=20):**<br>*Age (range):* 3 months to 10 years<br>*Gender:* Male n = 13, female n = 7<br><br>**Demographics of children from all identified datasets**:<br>*Mean age (n = 103):* 5.35 (± 4.65)<br>*Gender (n = 105):* 56.19% female<br><br>**Clinical characteristics from identified datasets:**<br>*Presentation (n=81):* Fever 77%; cough 59%; rhinorrhoea 17%; tachypnoea 12%; nausea/vomiting 12%; sore throat 12%; chills 11%; retraction 11%; diarrhoea 6%; fatigue/myalgia/weakness 2%<br>*Severity of infection (n = 102):* Asymptomatic 19%; Mild - Moderate 69%; Severe 12% | **Confirmed transmission**<br>Cluster with paediatric index case: 3/31 (9.7%)*<br>Number of secondary cases: 5<br>Cluster with paediatric index case, assuming that asymptomatic children are being mistakenly overlooked as the index case in familial clusters: 6/28 (21%)<br><br>**Mean time to transmission/symptoms onset**<br>Not reported<br><br>* Note: One case included here is also included in the case series by Cai et al.[1] |

## Table 2 Studies in childcare and school settings without transmission chain

| Author<br>Country<br>Study design | Population setting<br>Patient demographics<br>Clinical characteristics | Primary outcome results |
|---|---|---|
| **Desmet**[40]<br><br>**Belgium**<br><br>**Cross sectional study**<br><br>**DOI:** 10.1101/2020.05.13.20095190 | **Population Setting:**<br>84 children from 8 different daycare centres (1 in Brussels, 3 in Wallonia and 4 in Flanders) in Belgium shortly after the start of the epidemic.<br>Part of a larger nasopharyngeal carriage study that started in Belgium in 2016 to monitor changes in the proportions of pneumococcal serotypes in children between 6 and 30 months of age.<br><br>**Demographics:**<br>*Age:* 6-30 months<br>*Gender:* 43 (52.4%) female<br><br>**Clinical characteristics**<br>Common cold symptoms: 51.2% | **Transmission patterns**<br>Shortly after the start of the epidemic (29 Feb) and before the lockdown in Belgium (18 Mar) no (asymptomatic) carriage of SARS-CoV-2 was detected in a random sample of children attending daycare.<br><br>No information on COVID-19-like symptoms in household members or caregivers.<br><br>**Conclusion**<br>Results do not suggest a role of daycare attendance in early transmission. |
| **Fontanet**[39]<br><br>**France**<br><br>**Retrospective closed cohort study**<br><br>**DOI:** 10.1101/2020.04.18.20071134 | **Population Setting:**<br>661 pupils, parents, siblings and staff of a high school linked to a cluster of COVID-19 in Oise, approximately 8 weeks after the most likely introduction of SARS-CoV-2 in this community.<br>*School-based participants (n=326):*<br>Pupils*:* 240 (36.3%); Teachers: 53 (8%); school staff: 27 (4.1%)<br>*Parents and siblings (n=345):* parents 211 (31.9%); siblings 127 (19.2%).<br>*Others:* 3 (0.5%)<br>*Recruitment rate:* 326/878 (37%)<br><br>**Demographics:**<br>*Age:* median age: 37 years (IQR: 16-47); 2 participants > 65 years.<br>*Gender: 251 male (38%)*<br><br>**Clinical characteristics: all participants (n= 661)**<br>Respiratory symptoms up to 1 week before blood sampling: 452 (68.4%)<br>Major symptoms (fever, dry cough, dyspnoea, anosmia and ageusia): 321 (48.6%)<br>Minor symptoms (sore throat, rhinitis, muscle pain, diarrhoea, headache, asthenia): 131 (19.8%)<br>No symptoms: 209 (31.6%) | **Infection attack rate (IAR) (proportion of all participants with confirmed SARSCoV-2 infection):**<br>171/661, 25.9% (95% CI 22.6-29.4).<br><br>IAR was higher in the high school group (pupils, teachers, and school staff) than in parents and siblings (P <0.001).<br><br>*IAR by group*<br>Pupil (n=240): 92 (38.3%)<br>Teacher (n=53): 23 (43.4%)<br>School staff (n=27): 16 (59.3%)<br>Parent of a pupil (n=211): 24 (11.4%)<br>Sibling of a pupil (n=127): 13 (10.2%)<br>Other (n=3): 3 (100.0%)<br><br>*By age group*<br>≤14 (n=37): 1 (2.7%)<br>15-17 (n=205): 82 (40.0%)<br>18-44 (n=177): 39 (22.0%) |

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| | Most common symptoms: Rhinitis (38.3%), cough (35.4%), headache (30.9%), asthenia (29.6%), sore throat (26.8%), and fever (26.2%).<br>Hospitalisation rate: 5.3% (95% CI 2.4 –9.8)<br><br>**Participants with confirmed SARS-CoV-2 infection (n=171)**<br>Major symptoms: 70.8% (95% CI 63.3-77.5)<br>Minor Symptoms: 12.3% (95% CI 7.8-18.2)<br>No symptoms: 17.0% (95% CI 11.2 – 23.4) | 45-64 (n=239): 49 (20.5%)<br>≥65 (n=2) 0 (0.0%)<br><br>**Transmission patterns:**<br>Number of new cases decreased after beginning of the school holidays and again after local confinement measures were introduced in Oise. |

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