

## REVIEW ARTICLE

# Systematic review of COVID-19 in children shows milder cases and a better prognosis than adults

Jonas F. Ludvigsson<sup>1,2,3,4</sup>

<sup>1</sup>Department of Medical Epidemiology and Biostatistics, Karolinska Institutet, Stockholm, Sweden

<sup>2</sup>Department of Paediatrics, Orebro University Hospital, Orebro, Sweden

<sup>3</sup>Division of Epidemiology and Public Health, School of Medicine, University of Nottingham, UK

<sup>4</sup>Department of Medicine, Columbia University College of Physicians and Surgeons, New York, NY, USA

**Correspondence**

Jonas F Ludvigsson, Department of Medical Epidemiology and Biostatistics, Karolinska Institutet, 17177 Stockholm, Sweden.

Email: jonasludvigsson@yahoo.com

**Abstract**

**Aim:** The coronavirus disease 2019 (COVID-19) pandemic has affected hundreds of thousands of people. Data on symptoms and prognosis in children are rare.

**Methods:** A systematic literature review was carried out to identify papers on COVID-19, which is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), using the MEDLINE and Embase databases between January 1 and March 18, 2020.

**Results:** The search identified 45 relevant scientific papers and letters. The review showed that children have so far accounted for 1%-5% of diagnosed COVID-19 cases, they often have milder disease than adults and deaths have been extremely rare. Diagnostic findings have been similar to adults, with fever and respiratory symptoms being prevalent, but fewer children seem to have developed severe pneumonia. Elevated inflammatory markers were less common in children, and lymphocytopenia seemed rare. Newborn infants have developed symptomatic COVID-19, but evidence of vertical intrauterine transmission was scarce. Suggested treatment included providing oxygen, inhalations, nutritional support and maintaining fluids and electrolyte balances.

**Conclusions:** The coronavirus disease 2019 has occurred in children, but they seemed to have a milder disease course and better prognosis than adults. Deaths were extremely rare.

**KEYWORDS**

2019-nCoV, children, coronavirus, COVID-19, newborn, SARS-CoV2

## 1 | INTRODUCTION

In December 2019, there was an outbreak of a new infectious disease in Wuhan in the Hubei Province of China.<sup>1</sup> Coronavirus disease 2019 (COVID-19) is caused by the severe acute respiratory

syndrome coronavirus 2 (SARS-CoV-2), which was also previously known as 2019-nCoV. It is the seventh coronavirus.

On March 11, 2020, the World Health Organization (WHO) classified the outbreak as a pandemic. An interactive web-based real-time COVID-19 reporting system, known as a dashboard, has been set up

**Abbreviations:** COVID-19, coronavirus disease 2019; SARS, severe acute respiratory syndrome; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

© 2020 The Authors. *Acta Paediatrica* published by John Wiley & Sons Ltd on behalf of Foundation Acta Paediatrica.

by the Center for Systems Science and Engineering at Johns Hopkins University, Baltimore, Maryland, USA.<sup>2</sup> By March 18, 2020, there had been more than 2 00 000 confirmed cases and more than 8000 deaths due to COVID-19. This corresponds to a 4.0% case fatality rate.

A number of studies have reviewed symptoms and characteristics of adults with COVID-19. Although some of these studies have also included a smaller number of children,<sup>34</sup> the aggregated data on children with COVID-19 are rare. This paper summarises the findings of a systematic literature review on the current knowledge of COVID-19 in children.

## 2 | METHODS

### 2.1 | Search process

The review was carried out at the Karolinska Institutet, Stockholm, Sweden, and the Medline (used by PubMed) and Embase databases were searched for relevant terms related to COVID-19 and SARS-CoV2 in children. This search was carried out by two highly experienced librarians at the Institutet, and the search algorithm is presented in Appendix S1. There were 89 papers published in Medline between January 1 and March 18, 2020 and eight publications in Embase during the same period. Of those, 44 were deemed relevant to this review.<sup>5-48</sup> Also on March 18, but later during the day, the *New England Journal of Medicine* published a Letter to the Editor describing 1391 children assessed for SARS-CoV-2<sup>49</sup> (171 confirmed cases). That letter was also included in this review. The initial search was complemented by a further Medline search on March 19, 2020 by the author. This focused on 2019-nCoV, but this did not yield any additional studies (Appendix S1). This means that the current review was based on 45 scientific papers and letters. Most of the studies originated from China and it was notable that there were very few reports on children from Italy, Iran or South Korea, despite the large number of patients with diagnosed COVID-19 in those countries. There was no pre-specified protocol prior to the current review.

## 3 | RESULTS

### 3.1 | Background

The review with the largest number of positive COVID-19 cases was a Chinese paper by the *Chinese Novel Coronavirus Pneumonia Emergency Response Epidemiology Team* with 72,314 subjects, and this found that about 2% of the 44 672 confirmed cases of COVID-19 were children aged 0-19 years.<sup>49</sup> Of these, 0.9% were under the age of 10 years at diagnosis.<sup>49</sup> Italian data, published on March 18, 2020, reported that only 1.2% of 22 512 Italian cases with COVID-19 were children,<sup>50</sup> with no deaths. In fact, no deaths had been recorded below the age of 30 years in Italy.<sup>50</sup> Of 4226 COVID-19 cases detected in the United States until March 16,

### Keynotes

- The coronavirus disease 2019 (COVID-19) pandemic has affected hundreds of thousands of people worldwide, but data on how it affects children are rare.
- A systematic literature review identified 45 papers and letters published up to 18 March, and this showed that children have so far accounted for 1%-5% of diagnosed cases.
- Children often have milder disease than adults, and deaths have been extremely rare.

2020, 5% were children.<sup>51</sup> Children constituted less than 1% of all US hospitalisations.<sup>51</sup>

In the early stages of the epidemic, many children with COVID-19 were part of family clusters with the disease.<sup>18,45</sup> A large number of the cases described in this review originated from the Chinese city of Wuhan, which has nine million inhabitants. Wuhan is situated 1150 km south of Beijing and 840 km west of Shanghai and is the capital of the Hubei Province, which has 58 million inhabitants.

The incubation period in children is usually about two days with a range of 2-10 days.<sup>7</sup>

### 3.2 | Symptoms

The COVID-19 symptoms seem to be less severe in children than in adults.<sup>14</sup> One study by Dong *et al* examined 2143 children who were identified through laboratory tests by a combination of clinical manifestations and exposure history. Of these, 34.1% had laboratory-confirmed disease, while the remainder had clinically suspected disease.<sup>14</sup> Their symptoms were typical of acute respiratory infections and included fever, cough, a sore throat, sneezing, myalgia and fatigue. A number of children were wheezing. Another study from the Wuhan Children's hospital,<sup>52</sup> which probably overlapped with the Dong *et al* study,<sup>14</sup> reviewed 171 children with confirmed disease and presented more detailed symptoms. The most common symptoms were cough (48.5%), pharyngeal erythema (46.2%) and a fever of at least 37.5°C (41.5%).<sup>52</sup> The authors reported that 32.1% of the children had fever above 38°C and that most of these had 38.1°C-39.0°C.<sup>52</sup> Other studies have suggested that fever in children is usually below 39°C.<sup>7</sup>

Other symptoms<sup>52</sup> were diarrhoea (8.8%), fatigue (7.6%), rhinorrhoea (7.6%) and vomiting (6.4%). Four out of 171 children (2.3%) had low oxygen saturations of less than 92%. It should be noted that some COVID-19 publications have defined low oxygen saturation as below 93% or 94%. A substantial proportion of children demonstrated tachypnoea (28.7%) and tachycardia (42.1%) on hospital admission.<sup>52</sup> In a smaller case series of 10 Chinese children diagnosed outside Wuhan, eight had fever and six had a cough.<sup>7</sup> In a study that has only been published in Chinese so far, but was referenced by Yang *et al*,<sup>45</sup> 76.1% of 134 children with COVID-19 had fever.

### 3.3 | Disease severity

In the largest child case series so far,<sup>14</sup> more than 90% of the 2,143 children diagnosed with laboratory-verified or clinically diagnosed COVID-19 had asymptomatic, mild or moderate disease. Of the remainder, 5.2% had severe disease and 0.6% had critical disease.<sup>14</sup> According to the disease severity classification used by several Chinese publications, severe disease was defined as dyspnoea, central cyanosis and an oxygen saturation of less than 92%.<sup>14</sup> Critical disease required respiratory failure, sometimes with acute respiratory distress syndrome, shock and signs of multi-organ failure, such as encephalopathy, heart failure, abnormal coagulation and acute renal failure.

The prevalence of severe and critical disease was 10.6% in children aged <1 at diagnosis, 1-5 years (7.3%), 6-10 years (4.2%), 11-15 years (4.1%) and 16-17 years (3.0%).<sup>14</sup> Half of the children with critical COVID-19 in this study were less than one year of age,<sup>14</sup> and a high prevalence of severe disease was seen in very young children also in another study.<sup>13</sup> Of 171 children treated at Wuhan Children's Hospital, three (1.8%) required intensive care and all of those had underlying diseases. There was one case of hydronephrosis, one child was undergoing chemotherapy for leukaemia and another had intussusception. Yang *et al* have noted that the child with hydronephrosis in question had bilateral hydronephrosis with renal calculus.<sup>45</sup>

The percentage of 123 US children with COVID-19 in need of hospital admission was 1.6%-2.5% with no child needing intensive care.<sup>51</sup>

### 3.4 | Deaths

In a study of 44 672 confirmed COVID-19 cases up to February 11, 2020 (both adults and children), there were 965 deaths (2.2%). One child died in the 10-19 year age group,<sup>49</sup> and no children aged 0-9 years died. No more information was given about the child who died and whether the test for COVID-19 was performed before or after death. The authors mentioned that some testing was carried out retrospectively, but they were not any more specific. The dead child was probably the 14-year-old boy described in the paper by Dong *et al*.<sup>14</sup> The two research groups seem to have used the same data source, from China's Infectious Disease Information System<sup>49</sup> and the Chinese Center for Disease Control and Prevention,<sup>14</sup> and they seemed to cover much of the same time period.<sup>14,49</sup> Lu *et al* also reported the death of a 10-month-old child with intussusception and multi-organ failure.<sup>52</sup> None of the 123 US children with COVID-19 have died so far.<sup>51</sup> This means that this review was able to identify two deaths in children with COVID-19 up to March 18, 2020.

### 3.5 | Prognosis

One study reported that of 171 children diagnosed and admitted to hospital between January and 26 February, and 149 (87.1%) had been discharged by March 8, 2020.<sup>52</sup> In addition, a study by Cao

*et al* of 398 paediatric cases outside the Hubei Province claimed that most of the children recovered within 1-2 weeks.<sup>8</sup>

### 3.6 | Signs

Early studies in adult populations found increased liver enzymes, anaemia and increased inflammatory markers, such as erythrocyte sedimentation rate, C-reactive protein, procalcitonin and sometimes hyperglycaemia.<sup>53</sup> Data on laboratory markers in children with COVID-19 were rare, according to this review. The exception was a study by Henry *et al* that summarised the findings from 12 different studies on 66 children.<sup>17</sup> The authors found that 69.2% of the children had normal leucocyte counts and that neutrophilia (4.6%) and neutropenia (6.0%) were rare. Only two children (3.0%) experienced lymphocytopenia.<sup>17</sup> C-reactive protein and procalcitonin were increased in 13.6% and 10.6% of cases, respectively.<sup>17</sup> In a separate study that was not reviewed by Henry *et al*, lymphocytopenia was seen in 3.5% children.<sup>52</sup>

The clinical spectrum of children with COVID-19 has often been similar to that of influenza. This was demonstrated by a Chinese study of 366 children up to the age of 16 years, who were hospitalised with respiratory symptoms in the early phase of the epidemic.<sup>25</sup> Many of these children did not have COVID-19 but were instead diagnosed with the influenza A or B virus.<sup>25</sup>

### 3.7 | Computed chest tomography

Lu *et al* reported that ground-glass opacity was seen in a third of 171 diagnosed children.<sup>52</sup> Local or bilateral patchy shadowing was seen in 18.7% and 12.3%, respectively. Overall, 15.8% of children did not have symptoms of infections or radiological features of pneumonia.<sup>52</sup> A clinical diagnosis of pneumonia was made in 64.9% of the children.<sup>52</sup>

A second study reviewed five children<sup>23</sup> and reported that three had modest patchy ground-glass opacities on computed chest tomography. This was consistent with data reported by Liu *et al*.<sup>24</sup> Finally, Xia *et al* examined 20 children with computed tomography and found that 16 (80%) had some abnormalities, including halo signs, with ground-glass opacities seen in 12 patients (60%).<sup>42</sup> Another Chinese report, cited in Yang *et al*,<sup>45</sup> found viral pneumonia-like changes in 70.4% of 134 children undergoing chest imaging. It was unclear whether this was carried out using X-rays or computed tomography.

### 3.8 | Age

In the largest Chinese paediatric case series to date, of 2143 subjects, the median age at paediatric diagnosis was seven years.<sup>14</sup> The median was 6.7 years (range 1 day to 15 years) in 171 patients from the Wuhan Children's Hospital, who were better characterised.<sup>52</sup> Children of all ages can be infected, including newborn infants and young children.<sup>41</sup>

### 3.9 | Newborn infants with COVID-19

According to data from the National Health Commission of China, cited by Cai *et al*,<sup>8</sup> three neonatal cases were reported up to 20 February. At the same time, the total number of adult and paediatric cases in China was close to 80 000. The first neonate had fever and a cough for three days, and the second had a runny nose and vomiting for one week. The youngest child, who was diagnosed at 30 hours of age, after being born to an infected mother, had respiratory distress, but no fever.

Schwartz reviewed five publications from China and was able to identify 38 pregnant women with 39 offspring<sup>30</sup>: nine of the offspring were described in detail by Chen *et al*<sup>10</sup> and another 10 by Zhu *et al*.<sup>48</sup> Of the 39 offspring, 30 were tested for COVID-19 and all of them were negative. Schwartz noted that none of the pregnant women had developed severe pneumonia or died. The relatively mild disease course in the 38 pregnant women was consistent with the conclusion of a World Health Organization joint mission that investigated 149 pregnant women and found that pregnancy did not seem to be a risk factor for severe COVID-19 disease.<sup>54</sup> However, having COVID-19 during pregnancy may still have an impact on foetal outcome, namely foetal distress, potential preterm birth and respiratory distress.<sup>48</sup>

### 3.10 | Sex

Dong *et al*<sup>14</sup> reported that 56.6% of the 2143 patients in their study were boys.

### 3.11 | Comorbidities

A number of case reports have described comorbidities in children with COVID-19, but this review was unable to identify any study that quantified the prevalence of comorbidities in children. The section on disease severity in this paper notes that one study of 171 patients found that the three who required intensive care all had an underlying disease.<sup>52</sup>

### 3.12 | Diagnosis

COVID-19 has mostly been diagnosed using nasal or pharyngeal swabs or blood specimens that were positive for 2019-nCoV nucleic acid using real-time, reverse transcriptase-polymerase chain reaction assays. Alternative diagnostics have included genetic sequencing of specimens from the respiratory tract or blood consistent with SARS-CoV2.

Clinical diagnosis has been used for some cases, at least in China.<sup>14</sup> Diagnoses have been based on the presence of at least two symptoms (fever, respiratory symptoms, gastrointestinal symptoms or fatigue), combined with laboratory tests (normal or low white

blood cell count, and increased C-reactive protein) and an abnormal chest X-ray. Dong *et al* reported that other infectious diseases, such as influenza, were excluded before the patients were diagnosed with COVID-19, but no details were given.<sup>14</sup> This means that some of the cases reported in the Chinese papers did not have laboratory-verified diagnoses.

### 3.13 | Management and treatment

This review was not able to identify any drug trials or testing that was specifically aimed at children. Most publications that commented on treatment mentioned supportive treatment, including oxygen therapy<sup>7</sup> and antibiotics for bacterial superinfections.<sup>7</sup> Some,<sup>40,32</sup> but not all researchers,<sup>7</sup> recommended antiviral treatment. Antiviral treatment was clearly used in severe cases, but data on its efficacy in children with COVID-19 are missing.

Chinese physicians have recommended that children diagnosed with COVID-19 undergo a chest X-ray examination, preferably computed tomography.<sup>32</sup> A detailed epidemiological history should be taken. An extensive clinical examination should be performed and laboratory tests taken. Differential diagnoses include influenza virus, parainfluenza virus, adenovirus, respiratory syncytial virus, rhinovirus, human metapneumovirus and other known viral infections. They also include *mycoplasma pneumoniae* and chlamydia pneumonia and bacterial pneumonia.<sup>32</sup> Recommended treatment is outlined in Table 1.

One Chinese consensus group recommended discharge from hospital when three criteria were satisfied. These were that the child's body temperature had been normal for three days, the respiratory symptoms had improved and the SARS-CoV2 tests were negative. This group also stressed the importance of blocking transmission routes.<sup>32</sup> The importance of potential faecal transmission remains unclear.<sup>35</sup>

The secondary consequences of schools being closed and children being confined to their home were reviewed by Wang *et al*. The authors suggested that these measures may have negative effects on the children's physical and mental health. Such adverse effects included longer screen time, irregular sleep, less healthy diets that resulted in weight gain and loss of cardiorespiratory fitness.<sup>37</sup> In a study that was not related to the COVID-19 pandemic, Sprang *et al* reported that when children were quarantined and isolated after health-related disasters this could greatly increase the risk of post-traumatic stress disorder (data based on survey, focus groups and interviews from 398 parents).<sup>55</sup>

Zhang and Liu reviewed the potential interventions for COVID-19, but these were primarily aimed at adult patients.<sup>46</sup> In addition to nutritional support, the authors mention treatment with interferons, intravenous gamma globulin, thymosin alpha-1, thymopentin, levamisole, cyclosporine A and traditional Chinese medicine.<sup>46</sup> Of note, one in three patients treated with intravenous gamma globulin during the SARS 2003 epidemic developed venous thromboembolism.<sup>46</sup>

**TABLE 1** Recommended treatment, after Shen *et al*<sup>32</sup>

Breathing and airway	Other support	Infectious disease	Experimental treatment <sup>a</sup>
Oxygen supply	Caloric intake (for a review of nutritional interventions see Zhang and Liu <sup>46</sup> )	Antibiotics when there are bacterial superinfections	Interferon-alpha <sup>b</sup>
Inhalations	Water and electrolyte supply/balance		Lopinavir/litonavir <sup>b</sup>
Keeping respiratory tract unobstructed	Anti-pyretics if high fever		Interleukin-6 inhibitors <sup>b</sup>
Regular re-examination of airways			Arbidol, oseltamivir, ribavirin and other anti-influenza drugs <sup>b</sup>
Non-invasive/invasive respiratory support/mechanical ventilation including ECMO			Glucocorticoids
Fluid resuscitation, vasoactive drugs			Immunoglobulin
			Traditional Chinese medicine

<sup>a</sup>Not yet supported by the literature.

<sup>b</sup>Suggested dosages and pharmacological aspects of antiviral treatment of COVID-19 in children have been reviewed by Wang and Zhu.<sup>40</sup>

## 4 | DISCUSSION

This systematic review aimed to define the current evidence on COVID-19 in children. It identified 45 relevant publications, but I cannot rule out that there were other reports that my search algorithm may have missed. The literature search was carried out in English, but some identified papers presented results in Chinese but with English abstracts or summaries.

COVID-19 is either rare in children or it has not been diagnosed that often because this age group remain asymptomatic. One study suggested that 86% of all early COVID-19 infections in China remained undiagnosed.<sup>56</sup> While undiagnosed (undocumented) cases may have a lower transmission rate, their greater number suggests that they may have been the source of 79% of all early cases.<sup>56</sup> This may have implications if children with few symptoms are cared for by elderly people who constitute a risk group for COVID-19.

Children have represented some 2% of diagnosed cases in China,<sup>49</sup> 1.2% of cases in Italy<sup>50</sup> and 5% of COVID-19-positive cases in the United States.<sup>51</sup> These low figures were consistent with data from the SARS epidemic in 2003, when 6.9% of the positive cases were children, but none died. These data, from the e-SARS database in Hong Kong, were cited by Caselli *et al*.<sup>9</sup>

Earlier reports regarding adults with COVID-19 indicated a high prevalence of comorbidities.<sup>57</sup> For example, comorbidities were reported in 26.0% of 44 672 confirmed cases recorded by the *Chinese Novel Coronavirus Pneumonia Emergency Response Epidemiology Team*.<sup>49</sup> In adults, the most common comorbidities were hypertension, diabetes, cardiovascular disease and chronic respiratory disease. The report did not contain any information on the prevalence of these diseases in members of the general population who were a similar age. However, 67.2% of those who died from COVID-19 had a comorbidity and this higher prevalence<sup>49</sup> suggests that comorbidity is a risk factor for poor prognosis. This review only identifies case

reports of children with COVID-19 and comorbidities. In adults, cancer does not seem to be a risk factor for severe disease. One of the 171 hospitalised children in the Lu *et al* study<sup>44</sup> had leukaemia and was receiving ongoing chemotherapy when being diagnosed with COVID-19. Recommendations for the management of sick children who are diagnosed with COVID-19 are appearing quickly.<sup>44</sup> While death is extremely rare in children with COVID-19, it can occur in patients who are already very sick.

Coronavirus disease 2019 seems to have a milder course in children than in adults, and the obvious question is why? Several suggestions have been put forward. Children, especially smaller children, tend to have many viral infections. It is possible that repeated viral exposure supports the immune system when it responds to SARS-CoV-2. There have also been suggestions that the SARS-CoV-2 S protein binds to the angiotensin-converting enzyme (ACE) 2<sup>58</sup> and that children may be protected against SARS-CoV-2 because this enzyme is less mature at a younger age. The immune system undergoes substantial changes from birth to adulthood.<sup>59</sup>

The proportion of children with COVID-19 with elevated inflammatory markers has reportedly been low.<sup>17</sup> Severe cases of COVID-19 have been linked to increased levels of procalcitonin. Henry *et al* cited a Chinese paper that described how a young, very sick infant developed high interleukin-6 levels<sup>17</sup> and trials of interleukin-6 inhibitors are on their way. Other trials underway are examining the efficacy of the drugs remdesivir and chloroquine.

It is worth noting that studies focusing on adults have reported very high rates of lymphocytopenia. For example, Guan *et al* studied 1099 subjects and found that the rate was 83.2% in adults. However, only nine of the subjects were children.<sup>3</sup> These adult data contrasted with data from a study of 171 children, where only 3.5% had lymphocytopenia,<sup>52</sup> and the 3.0% in the case series published by Henry *et al*.<sup>17</sup> Future studies on the severity of COVID-19 should focus on the role of lymphocytes and their interaction with SARS-COV2. In the 2003 SARS epidemic, a study cited by Henry *et al*<sup>17</sup> reported that

lymphocytopenia was seen in 46% of children and that neutropenia was seen in 52%.

Lack of smoking in children is unlikely to explain the lower prevalence of severe COVID-19 in paediatric patients. Smoking does not seem to be a major feature in the pathogenesis of COVID-19 in adults.<sup>3</sup>

It is important to note that a large share of the scientific evidence so far has originated from China, and it is possible that country-specific factors there differ from children in some other countries. These include differences in day care and nutritional status and to what extent children come into contact with sick individuals.

An expert consensus statement published by the *World Journal of Pediatrics*<sup>32</sup> in late January 2020 included a number of recommendations (Table 1). However, these were clearly based on findings from adults. More recent studies on children with COVID-19 are likely to have an impact on future recommendations. For instance, the current paediatric recommendations in China do not reflect the milder disease course and the different laboratory findings seen in children.<sup>17,32</sup> It can therefore be questioned whether children with mild COVID-19, normal inflammatory markers and normal oxygen levels should really undergo computed tomography or chest X-ray.

Although the data are scarce, there seems to be little, if any, vertical intrauterine transmission from pregnant mothers to newborn infants.<sup>10</sup> Cord blood and placental tissue in COVID-19-positive mothers have been negative for SARS-CoV2,<sup>16</sup> and in a small series of 30 offspring none of the subjects developed COVID-19.<sup>30</sup> However, it is worth noting that many of these children were delivered by Caesarean section. To what extent maternal hypoxaemia in delivering mothers can lead to intrauterine asphyxia and preterm birth in the offspring seems to be unknown.

There have been reports of newborn infants who have tested positive to COVID-19 after being born mothers who have also tested positive.<sup>16</sup> Chinese neonatologists and obstetricians have recently proposed how to prevent and control COVID-19 infections in newborn infants.<sup>22,38,60</sup> Until now, there have been no reports of COVID-19 transmission within neonatal intensive care units, but although children seem to have less symptoms than adult patients also newborn infants can suffer from respiratory distress and are likely to transmit the disease if sick.<sup>8</sup>

The main strength of this study was that it used well-established databases and wide-ranging search terms to pick up as many studies as possible up to March 18, 2020. The main limitation was that we were unable to read the full text of some of the identified Chinese studies but had to rely on English language summaries or publications that referenced papers published in Chinese.

## 5 | CONCLUSION

In conclusion, this review identified 45 relevant studies on COVID-19 in children and the majority of the data were from China. Many of these studies seemed to overlap, with regard to the data they

presented, and some of the children who were diagnosed with COVID-19 did not have their diagnoses verified by laboratory tests. This has implications for prognosis. For example, Dong *et al* found that children with suspected COVID-19 had more severe disease than those with laboratory-confirmed disease. This suggests that a number of suspected COVID-19 cases may have been caused by other pathogens,<sup>14</sup> and it may still be too early to conclude that young children have a more severe COVID-19 than older children.

Our key findings were that the disease course in paediatric COVID-19 was milder than in adults, children had a better prognosis and deaths were extremely rare.

## ACKNOWLEDGEMENTS

We are grateful to the two librarians at the Karolinska Institutet University Library in Stockholm, Sweden, who performed the literature search.

## CONFLICTS OF INTEREST

The author is co-ordinating an unrelated study on behalf of the Swedish Inflammatory Bowel Disease Quality Register that has received funding from the Janssen Corporation.

## REFERENCES

1. Zhu NA, Zhang D, Wang W, et al. A Novel Coronavirus from Patients with Pneumonia in China, 2019. *N Engl J Med*. 2020;382(8):727-733.
2. Dong E, Du H, Gardner L. An interactive web-based dashboard to track COVID-19 in real time. *Lancet Infect Dis*. 2020. [https://doi.org/10.1016/S1473-3099\(20\)30120-1](https://doi.org/10.1016/S1473-3099(20)30120-1)
3. Guan W-J, Ni Z-Y, Hu YU, et al. Clinical characteristics of coronavirus disease 2019 in China. *N Engl J Med*. 2019;2020.
4. Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. *N Engl J Med*. 2020;382:1199-1207.
5. Anonymous. COVID-19 in children: initial characterization of the pediatric disease. *Pediatrics*. 2020;16:16.
6. Bajema KL, Oster AM, McGovern OL, et al. Persons evaluated for 2019 novel coronavirus - United States, January 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69:166-170.
7. Cai J, Xu J, Lin D, et al. A Case Series of children with 2019 novel coronavirus infection: clinical and epidemiological features. *Clin Infect Dis*. 2020;28:28.
8. Cao Q, Chen Y-C, Chen C-L, et al. SARS-CoV-2 infection in children: Transmission dynamics and clinical characteristics. *J Formos Med Assoc*. 2020;119:670-673.
9. Caselli D, Arico M. 2019-nCoV: polite with children! *Pediatric rep*. 2020;12:8495.
10. Chen H, Guo J, Wang C, et al. Clinical characteristics and intrauterine vertical transmission potential of COVID-19 infection in nine pregnant women: a retrospective review of medical records. *Lancet*. 2020;395:809-815.
11. Chen ZM, Fu JF, Shu Q. New coronavirus: new challenges for pediatricians. *World J Pediatr*. 2020;10:10.
12. Chen Z-M, Fu J-F, Shu Q, et al. Diagnosis and treatment recommendations for pediatric respiratory infection caused by the 2019 novel coronavirus. *World J Pediatr*. 2020;05:05.
13. Cui Y, Tian M, Huang D, et al. A 55-Day-Old Female Infant infected with COVID 19: presenting with pneumonia, liver injury, and heart damage. *J Infect Dis*. 2020;17:17.

14. Dong Y, Mo XI, Hu Y, et al. Epidemiological characteristics of 2143 pediatric patients with 2019 coronavirus disease in China. *Pediatrics*. 2020;16:16.
15. Hageman JR. The coronavirus disease 2019 (COVID-19). *Pediatr Ann*. 2020;49:e99-e100.
16. Han Y, Yang H. The transmission and diagnosis of 2019 novel coronavirus infection disease (COVID-19): a Chinese perspective. *J Med Virol*. 2020;06:06.
17. Henry BM, Lippi G, Plebani M. Laboratory abnormalities in children with novel coronavirus disease 2019. *Clin Chem Lab Med*. 2020;16:16.
18. Ji L-N, Chao S, Wang Y-J, et al. Clinical features of pediatric patients with COVID-19: a report of two family cluster cases. *World J Pediatr*. 2020;16:16.
19. Kam KQ, Yung CF, Cui L, et al. A well infant with coronavirus disease 2019 (COVID-19) with high viral load. *Clin Infect Dis*. 2020;28:28.
20. Lai C-C, Liu YH, Wang C-Y, et al. Asymptomatic carrier state, acute respiratory disease, and pneumonia due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2): facts and myths. *J Microbiol Immunol Infect*. 2020;04:04.
21. Lee P-I, Hu Y-L, Chen P-Y, et al. Are children less susceptible to COVID-19? *J Microbiol Immunol Infect*. 2020;25:25.
22. Li F, Feng ZC, Shi Y. Proposal for prevention and control of the 2019 novel coronavirus disease in newborn infants. *Arch Dis Child Fetal Neonatal Ed*. 2020;04:04.
23. Li W, Cui H, Li K, et al. Chest computed tomography in children with COVID-19 respiratory infection. *Pediatr Radiol*. 2020;11:11.
24. Liu H, Liu F, Li J, et al. Clinical and CT imaging features of the COVID-19 pneumonia: focus on pregnant women and children. *J Infect*. 2020;11:11.
25. Liu W, Zhang QI, Chen J, et al. Detection of COVID-19 in children in early January 2020 in Wuhan, China. *N Engl J Med*. 2020;12:12.
26. Lu Q, Shi Y. Coronavirus disease (COVID-19) and neonate: what neonatologist need to know. *J Med Virol*. 2020;01:01.
27. Ma X-L, Chen Z, Zhu J-J, et al. Management strategies of neonatal jaundice during the coronavirus disease 2019 outbreak. *World J Pediatr*. 2020;28:28.
28. Rasmussen SA, Smulian JC, Lednický JA, et al. Coronavirus disease 2019 (COVID-19) and pregnancy: what obstetricians need to know. *Am J Obstet Gynecol*. 2020;24:24.
29. Rothan HA, Byrareddy SN. The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. *J Autoimmun*. 2020;102433.
30. Schwartz DA. An analysis of 38 pregnant women with COVID-19, their newborn infants, and maternal-fetal transmission of SARS-CoV-2: maternal coronavirus infections and pregnancy outcomes. *Arch Pathol Lab Med*. 2020;17:17.
31. Schwartz DA, Graham AL. Potential maternal and infant outcomes from (Wuhan) coronavirus 2019-nCoV infecting pregnant women: lessons from SARS, MERS, and other human coronavirus infections. *Viruses*. 2020;12:10.
32. Shen K, Yang Y, Wang T, et al. Diagnosis, treatment, and prevention of 2019 novel coronavirus infection in children: experts' consensus statement. *World J Pediatr*. 2020;07:07.
33. Shen KL, Yang YH. Diagnosis and treatment of 2019 novel coronavirus infection in children: a pressing issue. *World J Pediatr*. 2020;05:05.
34. Sun K, Chen J, Viboud C. Early epidemiological analysis of the coronavirus disease outbreak based on crowdsourced data: a population-level observational study. *Lancet Dig Health*. 2020;2:e201-e208.
35. Tang AN, Tong Z-D, Wang H-L, et al. Detection of novel coronavirus by RT-PCR in stool specimen from asymptomatic child, China. *Emerg Infect Dis*. 2020;26:17.
36. Team C-NIRS. COVID-19, Australia: epidemiology report 6 (Reporting week ending 19: 00 AEDT 7 March 2020). *Commun Dis Intell*. 2018;2020:11.
37. Wang G, Zhang Y, Zhao J, et al. Mitigate the effects of home confinement on children during the COVID-19 outbreak. *Lancet*. 2020;04:04.
38. Wang L, Shi Y, Xiao T, et al. Chinese expert consensus on the perinatal and neonatal management for the prevention and control of the 2019 novel coronavirus infection (First edition). *Ann Trans Med*. 2020;8:47.
39. Wang S, Guo L, Chen L, et al. A case report of neonatal COVID-19 infection in China. *Clin Infect Dis*. 2020;12:12.
40. Wang Y, Zhu LQ. Pharmaceutical care recommendations for antiviral treatments in children with coronavirus disease 2019. *World J Pediatr*. 2020;12:12.
41. Wei M, Yuan J, Liu YU, et al. Novel coronavirus infection in hospitalized infants under 1 year of age in China. *JAMA*. 2020;14:14.
42. Xia W, Shao J, Guo YU, et al. Clinical and CT features in pediatric patients with COVID-19 infection: different points from adults. *Pediatr Pulmonol*. 2020;05:05.
43. Xu X-W, Wu X-X, Jiang X-G, et al. Clinical findings in a group of patients infected with the 2019 novel coronavirus (SARS-Cov-2) outside of Wuhan, China: retrospective case series. *BMJ*. 2020;368:m606.
44. Yang C, Li C, Wang S, et al. Clinical strategies for treating pediatric cancer during the outbreak of 2019 novel coronavirus infection. *Pediatr Blood Cancer*. 2019;2020:e28248.
45. Yang PU, Liu P, Li D, et al. Corona Virus Disease 2019, a growing threat to children? *J Infect*. 2020;03:03. <https://doi.org/10.1016/j.jinf.2020.02.024>.
46. Zhang L, Liu Y. Potential interventions for novel coronavirus in China: a systematic review. *J Med Virol*. 2020;92:479-490.
47. Zhao S, Ling K, Yan H, et al. Anesthetic management of patients with suspected or confirmed 2019 novel coronavirus infection during emergency procedures. *J Cardiothorac Vasc Anesth*. 2020;28:28.
48. Zhu H, Wang L, Fang C, et al. Clinical analysis of 10 neonates born to mothers with 2019-nCoV pneumonia. *Transl*. 2020;9:51-60.
49. Zhang Y. The Epidemiological Characteristics of an Outbreak of 2019 Novel Coronavirus Diseases (COVID-19) – China, 2020. Chinese Journal of Epidemiology (by The Novel Coronavirus Pneumonia Emergency Response Epidemiology Team). 2020.
50. Livingston E, Bucher K. Coronavirus disease 2019 (COVID-19) in Italy. *JAMA*. 2020.
51. Bialek S, Boundy E, Bowen V, et al. Severe outcomes among patients with coronavirus disease 2019 (COVID-19) – United States, February 12–March 16, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69:343-346.
52. Lu X, Zhang L, Du H, et al. SARS-CoV-2 infection in children. *N Engl J Med*. 2020.
53. Chen N, Zhou M, Dong X, et al. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. *Lancet*. 2020;395:507-513.
54. WHO. Report of the WHO-China Joint Mission on Coronavirus Disease 2019 (COVID-19). (<https://www.who.int/docs/default-source/coronaviruse/who-china-joint-mission-on-covid-19-final-report.pdf>; accessed: March 19, 2020), 2020.
55. Sprang G, Silman M. Posttraumatic stress disorder in parents and youth after health-related disasters. *Disaster Med Public Health Prep*. 2013;7:105-110.
56. Li R, Pei S, Chen B, et al. Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV2). *Science*. 2020.

57. Huang C, Wang Y, Li X, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan. *China. Lancet*. 2020;395:497-506
58. Wrapp D, Wang N, Corbett KS, et al. Cryo-EM structure of the 2019-nCoV spike in the prefusion conformation. *Science*. 2020;367:1260-1263.
59. Simon AK, Hollander GA, McMichael A. Evolution of the immune system in humans from infancy to old age. *Proc Biol Sci*. 1821;2015:20143085.
60. Liang H, Acharya G. Novel corona virus disease (COVID-19) in pregnancy: What clinical recommendations to follow? *Acta Obstet Gynecol Scand*. 2020;99:439-442.

#### SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

**How to cite this article:** Ludvigsson JF. Systematic review of COVID-19 in children shows milder cases and a better prognosis than adults. *Acta Paediatr*. 2020;00:1-8. <https://doi.org/10.1111/apa.15270>