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DIAGNOSTIC IMAGING IN NEWBORNS, CHILDREN AND ADOLESCENTS INFECTED WITH SEVERE ACUTE RESPIRATORY SYNDROME CORONAVIRUS 2 (SARS-COV-2): IS THERE A REALISTIC ALTERNATIVE TO LUNG HIGH-RESOLUTION COMPUTED TOMOGRAPHY (HRCT) AND CHEST X-RAYS? A SYSTEMATIC REVIEW OF THE LITERATURE

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Abstract—Chest computed tomography has been frequently used to evaluate patients with potential coronavirus disease 2019 (COVID-19) infection. However, this may be particularly risky for pediatric patients owing to high doses of ionizing radiation. We sought to evaluate COVID-19 imaging options in pediatric patients based on the published literature. We performed an exhaustive literature review focusing on COVID-19 imaging in pediatric patients. We used the search terms “COVID-19,” “SARS-CoV2,” “coronavirus,” “2019-nCoV,” “Wuhan virus,” “lung ultrasound (LUS),” “sonography,” “lung HRCT,” “children,” “childhood” and “newborn” to query the online databases PubMed, Medical Subject Headings (MeSH), Embase, LitCovid, the World Health Organization COVID-19 database and Medline Bireme. Articles meeting the inclusion criteria were included in the analysis and review. We identified only seven studies using lung ultrasound (LUS) to diagnose severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection in newborns and children. The studies evaluated small numbers of patients, and only 6% had severe or critical illness associated with COVID-19. LUS showed the presence of B-lines in 50% of patients, sub-pleural consolidation in 43.18%, pleural irregularities in 34.09%, coalescent B-lines and white lung in 25%, pleural effusion in 6.82% and thickening of the pleural line in 4.55%. We found 117 studies describing the use of chest X-ray or chest computed tomography in pediatric patients with COVID-19. The proportion of those who were severely or critically ill was similar to that in the LUS study population. Our review indicates that use of LUS should be encouraged in pediatric patients, who are at highest risk of complications from medical ionizing radiation. Increased use of LUS may be of particularly high impact in under-resourced areas, where access to chest computed tomography may be limited. (E-mail: costantinocost@yahoo.it) © 2021 World Federation for Ultrasound in Medicine & Biology. All rights reserved.

Key Words: COVID-19, SARS-CoV-2, Coronavirus, Lung ultrasound, Lung HRCT, Children, Newborn, Adolescent.

INTRODUCTION

December 2019 saw the start of the coronavirus disease 2019 (COVID-19) pandemic, the likes of which the world had not seen for almost 100 years, since the H1N1 flu pandemic (sometimes referred to as the “Spanish flu”). In common with that pandemic that spread worldwide in 1918, COVID-19 has relatively high mortality with contagion spreading around the globe. This virus, initially referred to as “the novel coronavirus,” belongs to the coronavirus family of single-stranded RNA viruses, ranging from the common cold to viruses that cause more serious diseases like Middle East respiratory syndrome and severe acute respiratory syndrome (SARS; Zaki et al. 2012; de Groot et al. 2013; World Health Organization 2018).

This disease and virus are still poorly understood despite a surge of published medical journal articles over the last few months. Like with any other illness, the objective should be to develop a rapid, accurate and
described in some populations (Guan et al. 2020; She et al. 2020). Computed tomography (CT) of the chest has been suggested as the screening method of choice because it can rapidly identify typical pulmonary findings of COVID-19. However, pathologic findings are often found later in the disease course, and CT is a poor imaging choice for follow-up or serial imaging (Fang et al. 2020), because of its cost and the stochastic effects secondary to repeated exposure to high doses of ionizing radiation, especially in pediatric patients (Norbedo et al. 2021).

Acute respiratory distress syndrome is uncommon in pediatric patients infected with COVID-19; most are completely asymptomatic, although vasculitis has been described in some populations (Guan et al. 2020; She et al. 2020). Ultrasound is an alternative imaging modality for respiratory complaints in pediatric patients, and there is considerable support in the literature for its use in a range of settings. A study in 2015 evaluated the usefulness and accuracy of lung ultrasound (LUS) in diagnosing and monitoring community-acquired pneumonia in children (Urbankowska et al. 2015). The researchers enrolled 106 children who all underwent LUS on the day of admission. Chest X-ray (CXR) was used as the criterion standard, and the resultant sensitivity and specificity were, respectively, 93.4% and 100%. The authors suggest, as others before them have, that LUS be considered the first-line imaging test for children with suspicion of community-acquired pneumonia.

LUS also proved to be accurate in a prospective study evaluating LUS in the diagnosis of pneumonia among children with a diagnosis of bronchiolitis (Biagi et al. 2018). Researchers evaluated 87 children and found a final diagnosis of pneumonia in 25. The sensitivity and specificity of LUS for pneumonia were, respectively, 100% and 83.0%. By comparison, CXR showed a sensitivity and specificity of 96% and 87.1%. This study showed LUS to have good accuracy in diagnosing pneumonia among children with a clinical diagnosis of bronchiolitis, performing as well as or better than CXR. A randomized, controlled prospective trial comparing LUS to CXR in 191 children who were suspected to have pneumonia (Jones et al. 2016). The authors noted a 38.8% reduction in CXR use with no cases of pneumonia missed, suggesting that LUS is a ready substitute for CXR in pediatric patients with possible pneumonia.

We sought to evaluate the use of LUS versus CXR and chest CT in children suspected to have COVID-19 pneumonia, as we believe that identifying an alternative diagnostic technique that is less invasive than radiation and more practical and immediate, especially in the pediatric population, is an important and interesting goal, based on published literature.

METHODS

We performed a systematic literature review of published research articles based on a search for the keywords “COVID-19,” “SARS-CoV2,” “coronavirus,” “2019-nCoV,” “Wuhan virus,” “lung ultrasound,” “sonography,” “lung HRCT,” “children,” “childhood” and “newborn” in the online databases PubMed, Medical Subject Headings (MeSH), Embase, LitCovid, the World Health Organization (WHO) COVID-19 database and Medline Bireme. Our review was drafted in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al. 2009; Fig. 1).

The inclusion criteria were English or Italian language and publication between 15 May 2019 and 7 October 2020; 51,600 articles were found with “COVID-19” as a key word. Limiting the search to lung ultrasound, lung high-resolution computed tomography (HRCT), CXR and COVID-19 keywords, we found 322 articles involving newborns, children and adolescents ages 0–18 y. After reading the entirety of these 322 manuscripts, we excluded articles that did not concern the study topic or that involved an adult population. Among full-text articles assessed for eligibility, we excluded news updates (six articles) and literature reviews (10 articles).

We included articles with pediatric patients with a diagnosis of SARS-CoV-2 infection, detected by real-time reverse transcription polymerase chain reaction assay, carried out in upper and lower respiratory specimens taken by nasopharyngeal swab, oropharyngeal swab or respiratory tract aspirates, who underwent at least one instance of diagnostic imaging of LUS, lung HRCT or CXR. Studies enrolling confirmed COVID-19 cases without performing diagnostic imaging were excluded.

Ultimately, 124 studies met the eligibility criteria for inclusion. We carried out data research, extraction and classification after reading through the entire manuscript and rating whether it was eligible for review. The following items were considered: authors and references, number of patients, age and sex, article type, symptoms and signs, patient population, severity of disease, correlation with clinic, LUS or CT/CXR description images, transducer used and areas scanned (for the studies involving LUS), period of recruitment and country where the study
was carried out. We included studies that obtained informed consent from each participant/guardian and were approved by an ethics committee or institutional review board, where applicable and indicated.

RESULTS

We identified only seven studies to date using LUS to diagnose SARS-CoV-2 infection in children. Each study involved small numbers of participants—10 (Parri et al. 2020), 10 (Musolino et al. 2020), 8 (Denina et al. 2020), 5 (Feng et al. 2020), 5 (Scheier et al. 2020), 3 (Gregorio-Hernández et al. 2020) and 3 (Vazquez Martínez et al. 2020)—for a total of 118 newborns and children (Supplementary Table S1, online only).

These studies used LUS and nasal swabs to diagnose SARS-CoV-2 and show the following results: 6.81% of children were asymptomatic, 81.81% had mild to moderate symptoms and 11.36% had severe symptoms. Using LUS, the authors describe the presence of B-lines in 50.0% of patients, sub-pleural consolidation in 43.18%, pleural irregularities in 34.09%, coalescent B-lines and white lung in 25%, pleural effusion in 6.82% and thickening of the pleural line in 4.55% (Supplementary Table S1, online only).
Studies using LUS to diagnose SARS-CoV-2 infection in children (Supplementary Table S1, online only) reveal a huge variety of presenting symptoms. Some were very frequent: 50.0% of them had fever, 41.0% had gastrointestinal symptoms, 38.8% had cough and 36.4% showed respiratory distress, dyspnea or tachypnea. Less frequently found are arthralgia (7%), chest pain (7%), headache (4.6%), rhinorrhea (4.6%), sore throat (3.0%), fatigue (2.3%), pharyngeal congestion (2.3%), anosmia (2.3%), dehydration (2.3%) and cyanosis (2.3%).

Regarding the use of CXR or lung CT in pediatric patients with COVID-19 infection, we identified 117 studies with a total of 2554 participants, with the following distribution: 10.81% were asymptomatic, 58.85% showed mild to moderate symptoms, 2.51% had severe symptoms, 2.43% were critical and 0.08% died. Authors reporting on CT use in pediatric patients describe the following findings most frequently: ground-glass opacity (GGO) in 25.58% of cases, normal CT imaging in 14.20%, patchy shadowing in 13.79% and pneumonia in 11.65%. There are low frequencies for other findings like consolidation, GGO + consolidation, crazy paving sign, pulmonary infiltration, the halo sign and others (Supplementary Table S2, online only).

Authors who report on CXR use in children report the following findings most frequently: pneumonia in 21.36%, normal CXR in 12.05%, GGO in 9.04%, pulmonary infiltration in 3.0%, pulmonary consolidations in 2.88%, interstitial abnormalities in 1.9% and lung texture enhancement in 1.64%. Findings such as GGO + consolidations, peribronchial cuffing, patchy shadowing and pleural effusion are reported less frequently (Supplementary Table S2, online only). However, in several cases descriptions of images findings are not included in the article, so these data are unavailable.

**DISCUSSION**

There is growing evidence that bedside LUS has high sensitivity and specificity in the diagnosis of most common respiratory diseases in children, including pneumonia, pleural effusion and bronchiolitis (Zimmerman et al. 2009; Marin et al. 2016), as well as that pediatric acute respiratory distress syndrome (PARDS) is a serious process in children leading to significant morbidity and a mortality of up to 20%. Correct, early diagnosis of PARDS is of critical importance for treating and monitoring patients. In fact, it is well known that diffuse interstitial lung involvement, despite normal lung auscultation and normal CXR results, may lead to hypoxemia and rapidly degenerate into respiratory failure, as described by the Writing Committee of the WHO Consultation on Clinical Aspects of Pandemic (H1N1) 2009 Influenza (2010).

The Pediatric Acute Lung Injury Consensus Conference was organized to better standardize diagnostic approaches, highlighting the importance of early and timely diagnosis. The result of the conference was a set of published diagnostic guidelines which focus on evaluation of PARDS. Given that the most common cause of PARDS is pneumonia (Pediatric Acute Lung Injury Consensus Conference Group 2015; Wang et al. 2018), it is important to realize that Lichtenstein et al. (2004) and Ord and Grikssatis (2019) have repeatedly demonstrated that LUS has higher sensitivity and specificity than CXR in diagnosing consolidations, pleural effusion and interstitial syndrome, which are typical in pneumonia. LUS has also been reported to be an important diagnostic tool in epidemic and pandemic respiratory infections (Zhang et al. 2015), long before the current COVID-19 pandemic. In fact, several studies in the literature demonstrate the importance of LUS in early recognition in pandemic influenza A (H1N1) pneumonia (Testa et al. 2012).

LUS can provide early detection of interstitial involvement in H1N1 viral pneumonia, even in patients with a normal chest radiograph (Testa et al. 2012). Furthermore, it is well known that ultrasound identification of an interstitial pattern and spared areas is strongly predictive of viral pneumonia (Volpicelli and Francisco 2009), and these findings are well correlated to lung CT findings (Lichtenstein et al. 1997; Lee et al. 2009; Cortellaro et al. 2012).

Tsung et al. (2012) report, in a prospective study, the use of ultrasound as an important real-time imaging triage tool in pediatric patients with acute respiratory syndrome secondary to the H1N1 influenza pandemic, and suggest that LUS may be useful for patient management during epidemics or pandemics of acute respiratory illnesses.

Additionally, Pereda et al. (2015) and Beree et al. (2019) have shown that LUS is an important resource in situations of viral and bacterial outbreaks of respiratory infection, and in particular, Pereda et al. (2015), in his meta-analysis has confirmed the high sensitivity (96%) and specificity (93%) of LUS for diagnosing pneumonia in children.

Ultrasound findings in COVID-19 follow a progression, with increasing severity correlated with worsening symptomatology and oxygenation. One of the first ultrasound hallmarks described in the early days of the pandemic was pleural changes which resulted in thickened, irregular pleura with periodic sub-pleural consolidations, correlating with chest CT findings (Peng et al. 2020). These findings have a predictable distribution and are more likely to be noted in lower lung fields anteriorly, higher laterally and then higher posteriorly in early or milder cases, and progress to involve the entire thorax with increasing severity (Alharthy et al. 2021). Furthermore, Mento et al. (2020) have demonstrated that the
posterior areas are very important for showing the crucial findings in people with COVID-19 infection, and that the 12-area approach is a better trade-off between acquisition time and accuracy than the 10-area approach. Also, Smargiassi et al. (2021) recommend inspecting multiple lung areas using LUS to perform a more accurate examination.

Owing to different approaches to using LUS to detect SARS-CoV-2 signs, Soldati et al. (2020) underline the need of a global unified and standardized equipment and acquisition protocol.

Reverberation artifacts similar to classic B-lines, but originating from abnormal pleura as opposed to cases of hydrostatic pulmonary edema, frequently coalesce on ultrasound examinations (Volpicelli and Gargani 2020). Additionally, as COVID-19 severity increases, LUS findings become more diffuse and are found in a broader distribution throughout the thorax. Interestingly, a reverse pattern is seen with recovery, as the distribution of pleural and lung abnormalities becomes sparser over weeks or months (Alharthy et al. 2020). Thus, while no new individual LUS findings are seen in COVID-19, the disease differs from others based on its specific distribution and significant pleural involvement with patchy appearance and slow resolution. Unlike in typical pneumonias, pleural effusions and hepatization are seen less frequently.

Given these studies, we feel that exclusive routine use of HRCT or CXR cannot be justified in children with suspected SARS-CoV-2 infection, and consideration should be given to LUS. LUS findings in children with suspected SARS-CoV-2 can clearly facilitate triage and immediate decision making regarding the need for respiratory isolation in a negative-pressure room without waiting for CXR or HRCT; in this pandemic scenario, movement of patients and exposure of health care professionals should be minimized to avoid new infections (Demi 2020).

Although a recent review (Liguoro et al. 2020) has demonstrated that the majority of pediatric patients with COVID-19 infection are asymptomatic or have mild to moderate illness, some of them are at risk for severe acute respiratory infection. The routine integration of LUS into clinical management could allow rapid identification of those who should start pharmacologic treatment.

Chodick et al. (2009) emphasize that the routine use of CXR or HRCT in childhood should be carefully evaluated, as increasing use of CT in childhood has raised concerns about potential radiation risks. Conversely, LUS is safe for children and medical personnel, and reduces patient movement across the hospital (Denina et al. 2020) because ultrasound machines can be used at triage and at the point of care and are easy to clean or sterilize. Unlike large CT or CXR equipment, it is easy to protect the entire point-of-care ultrasound machine and the probes with a plastic cover.

Although the American College of Radiology (“ACR Recommendations” 2020) currently recommends against using CT as a first-line screening test to diagnose COVID-19, reserving it for narrower and more specific clinical indications, our review of the literature shows that CT scan is frequently and extensively used in children as a diagnostic tool, in addition to reverse transcription polymerase chain reaction, which can be falsely negative (Merkus and Klein 2020). In fact, Yang et al. (2020) report that in children, some cases require two or even three tests to confirm COVID-19 infection, and that although positive reverse transcription polymerase chain reaction is considered the gold standard, children who receive a clinically false negative result are also a potential source of infection. Thus, the World Health Organization (2020) suggests, for clinically suspected patients, repetition of sample collection to improve test accuracy. On the other hand, it is unknown whether CT scanning has additional value as a screening tool to rule out COVID-19 infection in children with minor or no respiratory symptoms (Merkus and Klein 2020). Another worrying element emerged from our review: the discovery that in some cases, even with newborns, CT scanning was also used as a follow-up tool, repeating this examination even just 2 d after the first CT. In some cases CT was repeated for follow-up even in asymptomatic children or ones presenting with mild forms of infection. Decisions to repeat chest CT were justified simply by a positive nasopharyngeal swab for SARS-CoV-2.

Interestingly, only seven studies, with small cohorts, considered the use of LUS as a diagnostic tool in pediatric patients with suspected COVID-19. This limited use of LUS in children, if reflective of daily clinical practice, is in contradiction to available scientific evidence. This evidence has demonstrated that LUS in children is recognized as a valid imaging technique for the diagnosis and follow-up of pneumonia and acute respiratory failure (Lichtenstein and Mezière 2008; Pereda et al. 2015; Berce et al. 2019; Henrique de Souza et al. 2019). The sensitivity and specificity of LUS for diagnosing pneumonia are 100% and 83.9%, respectively, and when pneumonia consolidation size is >1 cm, the specificity of LUS has been demonstrated to be higher than that of CXR (98.4% vs. 87.1%; Biagi et al. 2018). However, Feng et al. (2020) have shown that the sensitivity of LUS is higher than that of CXR or chest CT in the diagnosis of pulmonary edema in neonates with COVID-19, and that LUS could be used for monitoring and evaluation of the disease. Interestingly, Perrone et al. (2021), in a cohort of 52 people with SARS-CoV2 infection, have demonstrated that LUS can represent an effective tool for monitoring and stratifying the prognosis of COVID-19 patients with pulmonary involvement.
Scheier et al. (2020) describe that lung point-of-care ultrasound is now a well-established diagnostic tool for children presenting to the pediatric emergency department with signs and symptoms concerning for Community Acquired Pneumonia (CAP). Vazquez Martinez et al. (2020) consider it very important to perform point-of-care ultrasound in SARS-CoV-2 pediatric infection as an immediate, repeatable, and non-invasive diagnostic tool.

Gregorio-Hernández et al. (2020) showed the findings of LUS monitoring after SARS-CoV-2 infection in three neonates, underlying the interest in studying this non-invasive approach in this population owing to the possibility of oligosymptomatic infection in infants and neonates (Canarutto et al. 2020). Demina et al. (2020) reveal a high concordance between radiologic and LUS findings, suggesting that LUS may be a reasonable method to detect lung abnormalities in children with COVID-19 infection. Moreover, the WHO estimates that most of the world’s population, about two-thirds of the planet, does not have access to basic radiology services like CXR (Silverstein 2016). Because the COVID-19 pandemic has global involvement, with a devastating impact in low-income countries where the availability of polymerase chain reaction tests and CXR is limited, LUS examination can play a decisive role in clinical and therapeutic decision making with pediatric patients with suspected coronavirus disease, thereby avoiding infection of further people in countries with resource-poor health systems and inadequate access to COVID-19 laboratory testing.

In conclusion, the results of our review encourage the use of diagnostic LUS in pediatric ages in a complementary way with clinical and laboratory investigations followed by chest CT, for confirmation in selected patients, using CT responsibly to reduce the stochastic risks as well as optimize diagnostic resources, especially in remote and under-resourced areas where access to chest CT may be limited.

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SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.ultsmed.2021.07.015.

REFERENCES

ACR recommendations for the use of chest radiography and computed tomography (CT) for suspected COVID-19 infection. American College of Radiology. March 11, 2020. Updated March 22, 2020. www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Recommendations-for-Chest-Radiography-and-CT-for-Suspected-COVID19-InfectionGoogleScholar. Accessed March 8, 2021.

Alharthy A, Abuhamedah M, Balhamar A, Faqhi F, Nasim N, Ahmad S, Noor A, Tamim H, Alqahthani SA, Al Saud AAAASBA, Kutso-giannis DJ, Brindley PG, Memish ZA, Karakitsos D, Blaivas M. Residual lung injury in patients recovering from COVID-19 critical illness: A prospective longitudinal point-of-care lung ultrasound study [e-pub ahead of print]. J Ultrasound Med 2020;29999:1–16. doi: 10.1002/jum.15653.

Alharthy A, Faqhi F, Abuhamedah M, Noor A, Naseem N, Balhamar A, Al Saud AAAASBA, Brindley PG, Memish ZA, Karakitsos D, Blai-

vas M. Prospective longitudinal evaluation of point-of-care lung ultrasound in critically ill patients with severe COVID-19 pneumo-
nia. J Ultrasound Med 2021;40:443–456.

Berce V, Tomazin M, Gorenjak M, Berce T, Lovrencič B. The usefulness of lung ultrasound for the aetiological diagnosis of community-acquired pneumonia in children. Sci Rep 2019;9:17957.

Biagi C, Pierantoni L, Baldazzi M, Greco L, Dormi A, Dondi A, Fal della G, Lanari M. Lung ultrasound for the diagnosis of pneumonia in children with acute bronchiolitis. BMC Pulm Med 2018;18:191.

Canarutto D, Priolo A, Russo G, Pitea M, Vigone MC, Barera G. COVID-19 infection in a paucisymptomatic infant: Raising the index of suspicion in epidemic settings. Pediatr Pulmonol 2020;55:E4–E5.

Chodick G, Kim KP, Shwarz M, Horev G, Shalev V, Ron E. Radiation risks from pediatric computed tomography scanning. Pediatr Endocri nol Rev 2009;7:29–36.

Cortellaro F, Colombo S, Coen D, Duca PG. Lung ultrasound is an accurate diagnostic tool for the diagnosis of pneumonia in the emergency department. Emerg Med J 2012;29:19–23.

de Groot RJ, Baker SC, Baric RS, Brown CS, Drosten C, Enjuanes L, Fouchier RAM, Galiano M, Gorbalenya AE, Memish ZA, Perlman S, Poon LLM, Snijder EJ, Stephens GM, Woo PCY, Zaki AM, Zambon M, Ziebuhr J. Middle East respiratory syndrome coronavirus (MERS-CoV): Announcement of the Coronavirus Study Group. J Virol 2013;87:7790–7792.

Demi L. Lung ultrasound: The future ahead and the lessons learned from COVID-19. J Acoust Soc Am 2020;148:2146.

Dennia M, Scolforo C, Silvestro E, Pruccoli G, Mignone F, Zoppo M, Ramenghi U, Garazzino S. Lung ultrasound in children with COVID-19. Pediatrics 2020;146:e20201157.

Fang Y, Zhang H, Xie J, Lin M, Ying L, Pang P, Ji W. Sensitivity of chest CT for COVID-19: Comparison to RT-PCR. Radiology 2020;296:E115–E117.

Feng XY, Tao XW, Zeng LK, Wang WQ, Li G. Application of pulmonary ultrasound in the diagnosis of COVID-19 pneumonia in neo-
nates. Zhonghua Er Ke Za Zhi 2020;58(5):347–350.

Gregorio-Hernández R, Escobar-Izquierdo AB, Cobas-Pazos J, Martinez-Gimeno A. Point-of-care lung ultrasound in three neo-
nates with COVID-19. Eur J Pediatr 2020;179:1279–1285.

Guam WN, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, Liu L, Shan H, Lei CL, Hui DSC, Du B, Li LJ, Zeng G, Yuan KY, Chen RC, Tang CL, Wang T, Chen PY, Xiang J, Li SY, Wang JL, Liang ZJ, Zeng YX, Wei L, Liu Y, Hu YH, Peng P, Wang J, Liu JY, Chen Z, Li G, Zheng ZJ, Qiu SQ, Luo J, Ye CJ, Zhu SY. Zhong NS; for the China Medical Treatment Expert Group for Covid-19. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med 2020;382:1708–1720.

Henrique de Souza T, Hersan Nadal JA, Oliveira Peixoto A, Mendes LA, Tsung JW. Feasibility and safety of substituting lung ultrasonography for chest radiography when diagnosing pneumonia in children. Emerg Med J 2012;29:19–23.

Lichtenstein D, Mezière G, Biderman P, Gepner A, Barré O. The comet-tail artifact: An ultrasound sign of alveolar-interstitial syn-
drome. Am J Respir Crit Care Med 1997;156:1640–1646.
Lichtenstein D, Goldstein I, Mougeno E, Cluzel P, Grenier P, Rouby JJ. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. Anesthesiology 2004;100:9–15.

Lichtenstein D, Mezière G. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: The BLUE protocol. Chest 2008;134:117–125.

Liguori I, Piloto C, Bonanni M, Ferrari ME, Puisiol A, Necorina A, Vidal E, Cogo P. SARS-COV-2 infection in children and newborns: A systematic review. Eur J Pediatr 2020;179:1029–1046.

Lu X, Zhang L, Du H, Zhang J, Li YY, Qu J, et al. SARS-CoV-2 infection for COVID-19 patchy pneumonia: Extended or limited evaluations?. J Ultrasound Med 2021;40:521–528.

Soldati G, Smargiassi A, Inchingolo R, Buonsenso D, Perrone T, Brigo DF, Perini S, Torri E, Mariani A, Messori CE, Ettori F, Mentha F, Cevi D, et al. Proposal for international standardization of the use of lung ultrasonography for COVID-19 patients: A simple, quantitative, reproducible tool. J Ultrasound Med 2020;39:1413–1419.

Su L, Ma X, Yu H, Zhang Z, Bian P, Han Y, Sun J, Liu Y, Yang C, Geng J, Zhang Z, Gai Z. The different clinical characteristics of coronavirus disease cases between children and their families in China—the character of children with COVID-19. Emerg Microbes Infect 2020;9:707–713.

Tagarro A, Epacliz M, Santos M, Sanza-Santecuencia FJ, Otheo E, Moralea C, Calvo C. Screening and severity of coronavirus disease 2019 (COVID-19) in children in Madrid, Spain. JAMA Pediatr 2020;175:316–317.

Testa A, Soldati G, Copetti R, Giannuzzi P, Portale G, Gentiloni-Silver E. Early recognition of the 2009 pandemic influenza A (H1N1) pneumonia by chest ultrasound. Crit Care 2012;16:R30.

Tsang JW, Kessler DO, Shah VP. Prospective application of clinician-performed lung ultrasonography during the 2009 H1N1 influenza A pandemic: Distinctive viral from bacterial pneumonia. Crit Ultrasound 2012;4:16.

Urbanowski E, Krenke K, Drobczyński L, Korczyński P, Urbankowski T, Krawiec M, Kraj G, Brzewski M, Kulus M. Lung ultrasound in the diagnosis and monitoring of community acquired pneumonia in children. Respir Med 2015;109:1207–1212.

Vazquez Martinez JL, Pérez-Caballero Macarrón C, Coca Pérez A, Tapia Moreno R, Otoo de Tejada E. Short report—usefulness of point-of-care ultrasound in pediatric SARS-CoV-2 infection. Eur Rev Med Pharmacol Sci 2020;24:7801–7803.

Volpicelli G, Francisco MF. Sonographic detection of radio-occult interstitial lung involvement in measles pneumonia. Am J Emerg Med 2009;27:128.e1–128.e3.

Volpicelli G, Gargani L. Sonographic signs and patterns of COVID-19 pneumonia. Ultrasound J 2020;12:22.

Wang J, Loh SW, Lee JH. Paediatric acute respiratory distress syndrome: Progress over the past decade. J Emerg Crit Care Med 2018;2:24.

WHO. 2018. WHO remembers Dr Carlo Urbani as a hero who fought SARS. https://www.who.int/neglected_diseases/news/Fifteen_years_after_the_passing_Dr_Carlo_Urbani/en/

World Health Organization (WHO). Clinical Management of Severe Acute Respiratory Infection (SARI) When COVID-19 Disease Is Suspected: Interim Guidance. 2020. https://www.WHO/2019-nCoV/covid-19/clinical/2020-4.

Writing Committee of the WHO Consultation on Clinical Aspects of Pandemic (H1N1) 2009 Influenza. Clinical aspects of pandemic 2009 influenza A (H1N1) virus infection. N Engl J Med 2010;362:1708–1719.

Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: Summary of a report of 72314 cases from the Chinese Center for Disease Control and Prevention. JAMA 2020;323(13):1239–1242.

Yang P, Liu P, Li D, Zhao D. Coronavirus disease 2019, a growing threat to children?. J Infect 2020;80:671–693.

Zaki AM, van Boheemen S, Bestebroer TM, Osterhaus ADME, Fouchier RA. Isolation of a novel coronavirus from a man with pneumonia in Saudi Arabia. New Engl J Med 2012;367:1814–1820.

Zhong YK, Li J, Yang JP, Zhang Y, Chen J. Lung ultrasonography for the diagnosis of 11 patients with acute respiratory distress syndrome due to bird flu H7N9 infection. Virol J 2015;12:176.

Zimmerman JJ, Alkhatr SR, Caldwell E, Rubenfeld GD. Incidence and outcomes of pediatric acute lung injury. Pediatrics 2009;124:87–95.

Silverstein J. Most of the world doesn’t have access to X-rays. The Atlantic 2016; September 27. Available at http://www.theatlantic.com/health/archive/2016/09/radiology-gap/501803 Accessed Sep 27, 2016.

Smargiassi A, Soldati G, Torri E, Mentha F, Milardi D, Del Giacoano P, De Matteis G, Burzo ML, Larici AR, Pompili M, Demi L. Lung ultrasonography for COVID-19 patchy pneumonia: Extended or limited evaluations?. J Ultrasound Med 2021;40:521–528.