Check for updates

Received: 27 June 2020 | Revised: 10 September 2020 | Accepted: 9 October 2020

DOI: 10.1002/ppul.25127

ORIGINAL ARTICLE: DIAGNOSTIC TESTING

Diagnostic value of lung ultrasonography in children with COVID-19

Mina Hizal MD[1] | Kubra Aykac MD | Burcu C. C. Yayla MD[2] | Arzu Yilmaz MD[3] | Demet Altun MD[4] | Habip E. Akkaya MD[5] | Gulsum I. Bayhan MD[6] | Aysegul N. C. Kurt MD[7] | Jale Karakaya PHD[8] | Yasemin Ozsurekci MD[9] | Mehmet Ceyhan MD[9]

[1]Department of Pediatric Pulmonology, Ankara Training and Research Hospital, University of Health Science, Ankara, Turkey

[2]Department of Pediatric Infectious Disease, Ankara Training and Research Hospital, University of Health Science, Ankara, Turkey

[3]Department of Pediatric, Ankara Training and Research Hospital, University of Health Science, Ankara, Turkey

[4]Department of Pediatrics, Faculty of Medicine, Ufuk University, Ankara, Turkey

[5]Department of Radiology, Ankara Training and Research Hospital, University of Health Science, Ankara, Turkey

[6]Department of Pediatric Infectious Disease, Yenimahalle Training and Educational Hospital, Yildirim Beyazit University, Ankara, Turkey

[7]Department of Pediatrics, Yenimahalle Training and Educational Hospital, Yildirim Beyazit University, Ankara, Turkey

[8]Department of Biostatistics, Hacettepe University, Ankara, Turkey

[9]Department of Pediatric Infectious Disease, Faculty of Medicine, Hacettepe University, Ankara, Turkey

Correspondence

Mina Hizal, Department of Pediatric Pulmonology, Ankara Training and Research Hospital, University of Health Science, Hacettepe Mh. Ulucanlar St. No: 89, 06230 Ankara, Turkey.

Email: minahizal@outlook.com

Abstract

Background: Lung ultrasound (LUS) has been successfully used in the diagnosis of different pulmonary diseases. Present study design to determine the diagnostic value of LUS in the evaluation of children with novel coronavirus disease 2019 (COVID-19).

Methods and Objectives: Prospective multicenter study, 40 children with confirmed COVID-19 were included. LUS was performed to all patients at admission. The chest X-ray and computed tomography (CT) were performed according to the decision of the primary physicians. LUS results were compared with chest X-ray and CT findings and diagnostic performance was determined.

Results: Of the 40 children median (range) was 10.5 (0.4–17.8) years. Chest X-ray and LUS were performed on all and chest CT was performed on 28 (70%) patients at the time of diagnosis. Sixteen (40%) patients had no apparent chest CT abnormalities suggestive of COVID-19, whereas 12 (30%) had abnormalities. LUS confirmed the diagnosis of pulmonary involvement in 10 of 12 patients with positive CT findings. LUS demonstrated normal lung patterns among 15 of 16 patients who had normal CT features. The sensitivity and the area under the receiver operating characteristics (ROC) curve (area under the ROC curve) identified by the chest X-ray and LUS tests were compared and statistically significantly different (McNemar's test: $p = .016$ and $p = .001$ respectively) detected. Chest X-ray displayed false-negative results for pulmonary involvement in 75% whereas for LUS it was 16.7%.

Conclusions: LUS might be a useful tool in the diagnostic steps of children with COVID-19. A reduction in chest CT assessments may be possible when LUS is used in the initial diagnostic steps for these children.

KEYWORDS

imaging, infections: pneumonia, TB, viral

Abbreviations: CT, computed tomography; COVID-19, novel coronavirus disease 2019; GGO, ground-glass opacities; LUS, lung ultrasound; rRT-PCR, real-time reverse transcriptase-polymerase chain reaction.

© 2020 Wiley Periodicals LLC

1 | INTRODUCTION

Since December 2019, there has been an outbreak of a new infectious disease called the novel coronavirus disease 2019 (COVID-19), which started in Wuhan, in the Hubei Province of China, and it quickly spread all around the world.[1] The diagnostic value of real-time reverse transcriptase-polymerase chain reaction (rRT-PCR) was lower than expected,[2] and studies demonstrated that chest computed tomography (CT) had high sensitivity, so it has become an important diagnostic tool for COVID-19.[3] However, after time recommendations have been made suggesting the appropriate use of imaging studies in selected populations.[4,5]

Only few of the total cases of COVID-19 were among patients aged under 18 years.[6] In children, the sign and symptoms of COVID-19 are milder than in adults.[6] There are limited data presently regarding the radiologic features of children with COVID-19.[7] There are two important concerns about radiography in children; risk of radiation exposure and obtaining low quality image due to poor patient cooperation.[8,9] Lung ultrasound (LUS) has been used in diagnosis of different lung diseases successfully in both adults and children.[10,11] The fact that COVID-19 lung involvement begins predominantly from peripheral regions of the lung creates an advantage in the detection of these lesions via LUS.[12]

Data regarding the role of LUS in the diagnosis and management of children with COVID-19 are lacking. The aim of the present study was to evaluate how LUS could be integrated into diagnostic steps of children with COVID-19 and compare its results with chest X-ray and CT.

2 | MATERIALS AND METHODS

This is a prospective, multicenter study conducted from April 2020 to May 2020 at four tertiary pediatric hospitals in Ankara, Turkey (Hacettepe University Children's Hospital, University of Health Science, Ufuk University Faculty of Medicine, Yildirim Beyazit University Yenimahalle Training and Educational Hospital). Both symptomatic and asymptomatic patients aged under 18 years with confirmed or suspected COVID-19 infections were evaluated at the time of admission to hospital. Only 40 children with confirmed COVID-19 infection were recruited in this study. Informed consent was obtained from all subjects (both from the parent and the child).

The medical team diagnosed suspected cases according to the presence of contact history and two criteria in clinical manifestations: (1) high body temperature, fatigue, respiratory manifestations, and dry cough; (2) abnormal findings in chest imaging; (3) abnormal laboratory tests—in the early stage, normal or decreased white blood cell count, or lymphopenia; (4) symptoms not fully explained by other pathogens. Suspected cases with positive rRT-PCR or serum-specific antibodies for SARS-CoV-2 were accepted as confirmed cases.[13]

The study was approved by the Research Ethics Committee as well as the Public Health Agency, of the Ministry of Health of Turkey. Demographic data, contact history, and clinical symptoms were collected by research teams through interviews with the children and parents. Hematologic parameters and standard C-reactive protein (detection limit 5 mg/L) were analyzed in the clinical laboratories of each study center at the time of admission. Neutrophilia and lymphopenia were determined according to age groups.[14] Data from the medical records were extracted by the research teams at each center. The patients were categorized into five groups based on the recent classification provided by Shen et al.[13]: (a) asymptomatic infection (no clinical symptoms and imaging abnormality); (b) acute upper respiratory tract infection (respiratory symptoms without pneumonia); (c) mild pneumonia (respiratory symptoms ± high fever + pneumonia; not fulfilling the criteria of severe pneumonia); (d) severe pneumonia (dyspnea, oxygen saturation < 92%, impaired consciousness, dehydration with feeding difficulty, chest CT features of bilateral or multilobar infiltrates and rapid progression or pleural effusion); (f) critical cases (patients who required intensive care unit care for mechanical ventilation, organ failure, or shock).

2.1 | Equipment and procedure

LUS was performed to all patients at the time of diagnosis at the bedside by a single pediatric pulmonologist who was unaware of the symptoms, and imaging findings and serial images and video records were obtained. The chest X-ray and CT were performed according to the decision of the primary physician of patients without knowing the LUS results. Chest X-ray and CT at the time of diagnosis were checked by a separate experienced (>5 years) radiologist who was blinded to the patients' clinics and sonography results. Chest X-rays were evaluated for the presence of consolidation, lung opacity, and pleural effusion. The CT findings were evaluated for distribution, the presence of ground-glass opacities (GGO), nodules, consolidation with surrounding halo sign, fine mesh shadow, peribronchial cuffing or thickening, presence of interstitial appearance, and pleural effusion.

Typical chest CT features for COVID-19 are expected as multilobular and bilateral GGO, predominantly with posterior or peripheral distribution and mainly located in the lower lobes, patchy consolidation with or without GGO, interlobular septal thickening, pleural thickening, crazy paving pattern, subpleural bands, vacuolar sign, and vascular enlargement.[15–18] Enumerated LUS records were evaluated by a pediatric pulmonologist and an experienced radiologist who were blinded to the clinical examinations and imaging studies and each other's findings. In case of discrepancy between sonographic results, they decided in conclusion.

LUS was performed using a 5–3.5 MHz convex array probe or 10–7.5 MHz linear array probe depending on the age and size of the children. A portable wireless color ultrasonic device was used with a connection to a mobile phone. The probes and phone were covered with film and 75% alcohol were used to clean the devices, as seen in Figure 1. Children were investigated in sitting and lateral decubiti positions. Infants were examined seated on a caregiver's lap. Scans

FIGURE 1 Portable wireless linear and convex probes (covered by film) [Color figure can be viewed at wileyonlinelibrary.com]

started from upper zones and moved downwards until the subdiaphragmatic area.

All intercostal spaces of the upper and lower parts of the anterior, lateral, and posterior regions of each hemithorax were examined. Each zone was then scanned along anatomic lines: midclavicular, parasternal, anterior axillary, midaxillary, posterior axillary, paravertebral, and mid-scapular.[19,20] The probe was placed perpendicular, oblique, and parallel to the ribs. The examiners defined the following signs: A-line, normal sliding of lung, B-line distribution and number, pleural line abnormality, consolidation, white lung sign, pleural effusion, and atelectasis.

Normal lung: multiple horizontal A-line (reverberation artefacts of the pleural line appear as hyperechoic parallel line to the pleural, horizontal artifacts) + normal sliding of the pleural line.

B-lines or comet-tail artefacts: hyperechoic vertical lines arising from the pleural line and moving with sliding lung (represent interstitial syndrome). Detection of three or more B-lines in same view or confluent B line were accepted as abnormal.[21,22]

2.2 | Statistical analysis

The descriptive statistics are presented as median with min–max for continuous variables and frequencies with percentages for categorical variables. Sensitivity, specificity, predictive values (positive predictive value [PPV], negative predictive value [NPV]), likelihood ratios (LR+, LR−) and, their 95% confidence intervals (CIs) were calculated for chest X-ray and LUS according to CT with MedCalc Statistical Software. Sensitivity, specificity, PPV and NPV are expressed as percentages. CIs for sensitivity, specificity are “exact” Clopper–Pearson CIs. CIs for the likelihood ratios are calculated using the “log method” as given on page 109 of Altman et al.[23] CIs for the predictive values are the standard logit CIs given by Mercaldo et al.[24] In addition, the overall diagnostic performance of chest X-ray and LUS in determining two classes (positive–negative) according to tomography (CT) was assessed through receiver operating characteristics (ROC) analysis. The area under the ROC curve (AUC) and its CIs was calculated. Performance was interpreted according to follows: AUC < 0.7—poor, AUC = 0.7–0.8—fair, AUC = 0.8–0.9—good, AUC = 0.9–1.0—excellent. The significance level was set at $p < .05$. Analyses were done in IBM SPSS Statistics, version 23.

The power calculation was performed to determine the adequacy of the sample size in the study with the NCSS PASS 11.0 program. McNemar's test was used to understand the test characteristics of X-ray and LUS and to compare differences in the sensitivity of the two methods, with the alpha risk of 5%, the odds ratio was obtained as 71.62 as the effect size measure for the McNemar's test, and power calculation was approximately 75%. For comparison of the AUCs, type 1 error (alpha) was 5%, the difference between the two areas was 0.2910, the power calculation was approximately 86%.

3 | RESULTS

Of the 40 cases, the median age of the children was 10.5 (0.4–17.8) years. Five patients were aged under 2 years and twelve were aged under 5 years. There were 18 (45%) males and 22 (55%) females. The most common symptom was dry cough, which was present in 24 (60%). Two patients had underlying disease; one had osteopetrosis and the other had childhood asthma. The patients were classified into five groups according to their severity; asymptomatic infection (n = 4, 10%), acute upper respiratory tract infection (n = 24, 60%), mild pneumonia (n = 10, 25%), severe pneumonia (n = 0), and critical cases (n = 2, 5%). The demographic data, clinical features, laboratory, and radiographic features of the children and are presented in Table 1.

Chest X-ray was performed on all patients. Abnormal chest X-ray findings (consolidation, lung opacity, and pleural effusion) was detected in four patients (three had bilateral consolidations and hazy increased opacities). Chest CT was performed on 28 (70%) patients at the time of diagnosis. Sixteen (40%) patients had no apparent chest CT abnormalities suggestive of COVID-19, whereas twelve (30%) had abnormalities in chest CT imaging; bilateral GGO and consolidations were the most frequent findings, mostly located in the posterior and lower parts of both lungs.

LUS was performed on all 40 patients without any problems. The time taken to perform LUS was 4–10 min. In 29 (72.5%) patients, LUS showed normal A-line pattern with sliding lung, B-line patterns were observed in 11 (27.5%) patients, thickened pleural line was visualized in 2 (5%) patients, and subpleural consolidation was detected in 4 (10%) patients, as seen in Table 2 and Figure 2. LUS confirmed the diagnosis of pulmonary involvement in 10 of 12 patients with positive CT findings; despite chest X-ray of 7 of 10 of them was normal. Also, the lesion size in patients for whom LUS was not able to suggest any lung involvement was less than 1 cm shown by CT. In one

TABLE 1 Clinical features and demographic characteristics of pediatric patients with COVID-19

	Total cases (*n* = 40)	Asymptomatic infection (*n* = 4)	Acute upper respiratory tract infection (*n* = 24)	Mild pneumonia (*n* = 10)	Severe pneumonia and critical cases (*n* = 2)
Age, median (min–max) (years)	10.5 (0.4–17.8)	10.7 (7.8–14.5)	8.5 (0.4–17)	13.7 (0.8–17.8)	10.6 (7.8–13.5)
Male, *n* (%)	18 (45%)	2 (50%)	10 (41.6)	5 (50%)	1 (50%)
Family members with COVID-19, *n* (%)	37 (92.5%)	4 (100%)	22 (91.6%)	10 (100%)	1 (50%)
Underlying disease					
No disease (healthy)	38 (95%)	4 (100%)	24 (100%)	9 (90%)	1 (50%)
Underlying disease	2 (5%)	–	–	1 (10%)	1 (50%)
Symptoms, *n* (%)					
Fever	21 (52.5%)	–	13 (54.1%)	6 (60%)	2 (100%)
Dry cough	24 (60%)	–	14 (58.3%)	8 (80%)	2 (100%)
Dyspnea or tachypnea	3 (7.5%)	–	1 (4.1%)	0	2 (100%)
CRP (mg/L)	0.8 (0.01–97)		0.4 (0.01–97.0)	1.3 (0.08–45.0)	5.8 (0.7–10.7)
Laboratory findings, *n* (%)					
Neutropenia	7 (17.5%)	0	3 (12.5%)	2 (20%)	2 (100%)
Lymphopenia	10 (25%)	1 (25%)	3 (12.5%)	5 (50%)	1 (50%)
High CRP	8 (20%)	0	4 (16.6%)	3 (30%)	1 (50%)
Chest X-ray, *n* (%)					
Normal	36 (90%)	3 (75%)	24 (100%)	9 (90%)	–
Unilateral consolidation	1 (2.5%)	1 (25%)	–	–	–
Bilateral multifocal consolidation	3 (7.5%)	–	–	1 (10%)	2 (100%)
Thorax computed tomography, *n* (%)					
Normal	16 (40%)	2 (50%)	14 (58.3%)	–	–
Ground-glass opacities	12 (30%)	–	–	10 (100%)	2 (100%)
Pulmonary consolidation	6 (15%)	–	–	4 (40%)	2 (100%)
Lung ultrasound, *n* (%)					
Normal (A-line + normal sliding)	29 (72.5%)	4 (100%)	23 (95.8%)	2 (20%)	–
Interstitial B-lines pattern	11 (27.5)		1 (4.1%)	8 (80%)	2 (100%)
Pulmonary consolidation	4 (10%)	–	–	2 (20%)	2 (100%)

Note: Continuous variables are presented as median (min–max)

Abbreviations: COVID-19, novel coronavirus disease 2019; CRP, C-reactive protein; IQR, interquartile range.

TABLE 2 LUS findings and results (*n* = 40)

LUS appearance	Number (%)
A-line and normal sliding lung	29 (72.5)
B-line in various pattern	11 (27.5)
Consolidation	4 (10)
Thickened or irregular pleural line	2 (5)
Pleural effusion	0

Abbreviation: LUS, lung ultrasound.

patient, the LUS examination showed an increased B-line in the right lower lobe despite normal chest CT findings. LUS demonstrated normal lung patterns among 15 of 16 patients who had normal CT features, as seen in Figure 3. Three of four patients with abnormal chest X-ray had pulmonary involvement in CT.

The performance of LUS as a diagnostic test was found to be good; AUC = 0.88 (95% CI: 0.75–1.01), PPV = 90.9% (95% CI: 58.7–99.8), and NPV = 88.2% (95% CI: 63.6–96.5), sensitivity = 83.33% (95% CI: 51.6–97.9), specificity = 93.75% (95% CI: 69.8–99.8). The diagnostic performance of chest X-ray and LUS compared with CT are summarized in Table 3. The sensitivity and

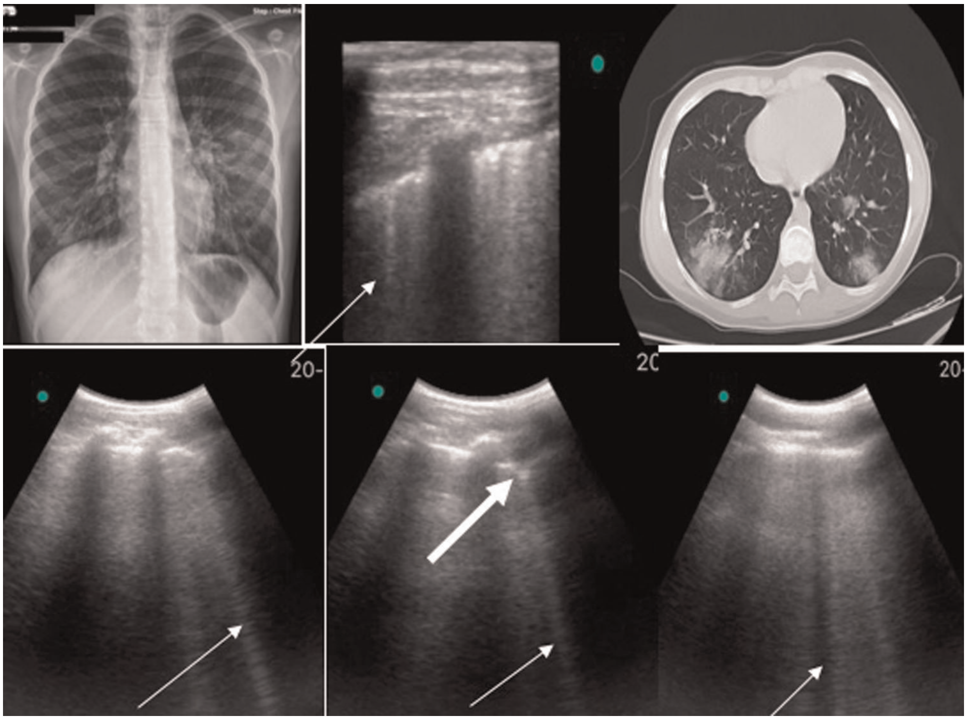

FIGURE 2 Eight-year-old female evaluated for family contact who had fever and cough. SPO2 at admission was 98%. (A) Chest X-ray demonstrated bilateral hazy opacities and (B) LUS demonstrated multiple B lines (thin arrows) and consolidation and pleural irregularity (thick arrow). (C) Chest computed tomography showed multiple scattered ground-glass opacities shadows with consolidation in the periphery zone of both lungs [Color figure can be viewed at wileyonlinelibrary.com]

AUC identified by the chest X-ray and LUS tests were compared and statistically significantly different (McNemar's test: $p = .016$ and $p = .001$, respectively) detected. Chest X-ray and LUS displayed false-positive results for pulmonary involvement in 6.25%. Chest X-ray displayed false-negative results for pulmonary involvement in 75%, whereas for LUS it was 16.7%.

Among the total 40 children, 2 received mechanical ventilation and were followed in the intensive care unit. All the other patients were in a stable condition in hospital or were discharged home after follow-up in general wards.

4 | DISCUSSION

To the best of our knowledge, this is the first prospective multicenter study in the pediatric age group to evaluate the role of LUS in the diagnostic pathway of children with COVID-19. In present study, we demonstrate that LUS is able to detect pulmonary involvement related to COVID-19; therefore, ultrasound imaging may be another potential diagnostic tool in pediatric patients with COVID-19, which is particularly beneficial for reducing radiation exposure, decreasing transport, and preventing the spread of disease, concurrently helping physicians with bedside evaluations of children during this pandemic.

The diagnostic value of rprt-PCR was found lower than expected.[2] Literature reports demonstrate that chest X-ray had low sensitivity in the diagnosis of pulmonary involvement of COVID-19.[24] Also, certain studies showed that chest CT had high sensitivity and could even detect lung abnormalities in asymptomatic patients, thus, chest CT became one of the important diagnostic tool for COVID-19 in the initial stage of pandemic.[3,17] However, a great majority of children have mild or moderate disease without pulmonary involvement, compatible with our results.[13,25] In fact, lack of evidence about radiologic evaluation of children in COVID-19, frequent use of CT scan a in large studies and inadequate experience in management of disease are factors that predispose to overuse of CT scan in children similar to present study.[25,26]

Due to extensive environmental contamination by COVID-19, use of many conventional diagnostic methods are limited in the evaluation steps of these patients.[12,27] Use of a stethoscope or transport of patients for radiologic imaging increase the nosocomial transmission risk of the virus.[28] These problems led us to consider the idea of patients being evaluated at their bedsides by their primary physicians. The results of the present study demonstrate that LUS can be used as an alternative diagnostic bedside method for children during this COVID-19 pandemic.

Few studies conducted so for in adults have shown that LUS findings were correlated with chest CT, and LUS was a useful diagnostic tool in adult patients with COVID-19 pneumonia.[29,30] However, there is only two recent brief reports which that compared LUS and radiography features of few children with COVID-19.[26,31] The results of our study revealed that, in line with previous results, LUS performed at the time of diagnosis was able to identify a substantial

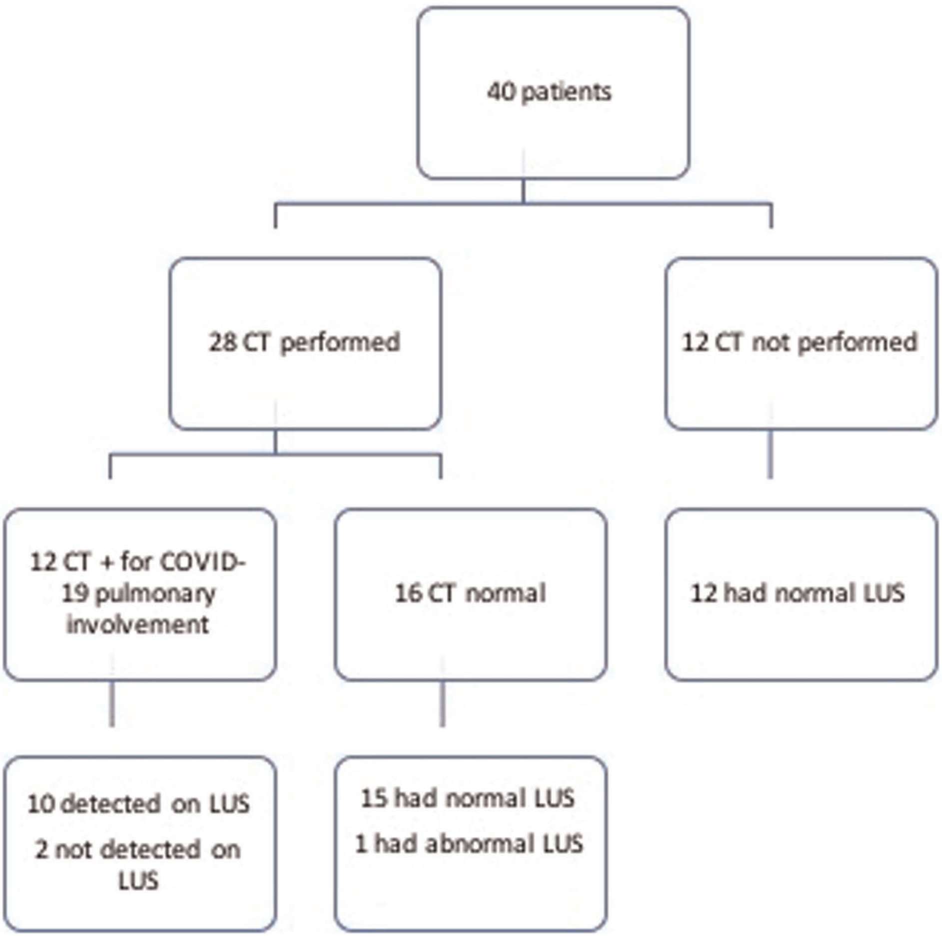

FIGURE 3 Lung ultrasound (LUS) and computed tomography (CT) results of pediatric patients with novel coronavirus disease 2019 (COVID-19) [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Respective performance of lung ultrasound and chest X-ray in the diagnosis of COVID-19 pulmonary involvement according to the chest CT scan diagnosis

Measures of performance	LUS	Chest X-ray	*p* Value
Sensitivity (95% CI)	83.33% (51.6–97.9)	25% (5.5–57.2)	**.016**
Specificity (95% CI)	93.75% (69.8–99.8)	93.75% (69.8–99.8)	1.000
AUC (95% CI)	0.885 (0.759–1.011)	0.594 (0.452–0.736)	**.001**
PPV (95% CI)	90.9 (59.5–98.5)	75 (26.17–96.21)	–
NPV (95% CI)	88.2 (67.7–96.4)	62.5 (54–70.29)	–
LR+ (95% CI)	13.33 (1.97–90.4)	4 (0.47–33.86)	–
LR− (95% CI)	0.18 (0.05–0.6)	0.8 (0.56–1.14)	–
Youden index	0.77	0.18	–

Note: The bold values are significant at $p < .05$.

Abbreviations: AUC, area under curve; CI, confidence interval; COVID-19, novel coronavirus disease 2019; LR, likelihood ratios; LUS, lung ultrasound; NPV, negative predictive value; PPV, positive predictive value.

number of children with pulmonary involvement. Although LUS is not as sensitive as lung CT, the results of our study indicate that it could be useful to rapidly identify pediatric patients with pulmonary involvement. It should be noted that LUS may not show abnormal findings in patients with mild pulmonary involvement.

The frequency of pulmonary involvement detected in radiography in pediatric patients with COVID-19 varies between studies, ranging from 32.7% to 80%.[7,32,33] In the present study, pulmonary involvement was detected in nearly one-third of the children using radiography; however, there was no pulmonary involvement in a significant portion of the patients. Children with respiratory symptoms need to be evaluated carefully. Furthermore, close follow-up of patients and serial imaging are not always possible during outbreaks.[28] Bedside diagnostic tools, therefore, become more important because they provide physicians with additional information under pandemic conditions. Importantly, the results of our study showed that LUS could be performed safely without any problems for children at their bedside in the presence of their families during the current pandemic. It was observed that all children who received CT scans with subsequent normal results also had normal results in their LUS. Such a result achieved by our study suggests that LUS could facilitate decision-making regarding pulmonary involvement for physicians to discern patients with no pulmonary involvement, and could reduce the number of chest CT scans in pediatric patients during the pandemic.

Based on limited data obtained from adult studies, characteristic findings of LUS in COVID-19 are irregular thickened pleural lines, confluent B line artefacts caused by interstitial inflammation, and consolidations, consistent with the results of the present study.[12,30] The fact that COVID-19 lung involvement begins predominantly in the peripheral region and frequently involves the pleural surface, creates an advantage in the detection of these lesions via LUS.[12]

Moreover, our study proves to be rather significant because it is use portable wireless devices connected to cell phones for the evaluation of pediatric patients with COVID-19. Both the device and cell phones could be easily wrapped in stretch films and readily disinfected following the procedure. A point that needs specific attention is that ultrasound gel should be applied on the probe before the wrapping. In addition, the use of the device with a cell phone enabled a single operator to perform the procedure, as was the case in our study, and less healthcare staff was exposed to risks. Buosenso et al.[28] also recently underlined the possibility that such devices could be useful in the COVID-19 pandemic.

LUS, as an imaging method that can be helpful in the management of patients, is also easily performed at the bedside. Its most important disadvantage, however, is the fact that it is operator-dependent and is time consuming. Another important limitation of LUS is its inability to detect consolidations that do not extend to the pleura, behind the skeletal structures. Also, features such as cardiac shape, hyperinflation, and airway positions cannot be evaluated via LUS.[21] Therefore, evaluating patients' LUS results in line with clinical symptoms and chest X-ray findings may be useful in assisting in decision-making regarding the condition of patients.

This study has several limitations. The sample size of the study was small due to difficulty to perform a multicenter prospective study during the surge of the pandemic. Also, the number of patients with pneumonia is low and no control group was included. Moreover, the low number of patients is reflected in our wide 95% CIs and therefore, our preliminary results need to be validated by further studies. We could not determine LUS sensitivity and specificity for all patients because it is not ethical to perform CT on everyone. Selection bias during sampling may have occurred because physicians were more likely to perform further investigations to more symptomatic patients or at busier working times. Thus, some asymptomatic or less symptomatic patients did not have CT imaging, and information about them is lacking. The present study was conducted using portable probes and mobile phones and this could have affected the image quality obtained. In the present study, since the final decision was made in conclusion in case of discrepancy between sonographic results, the kappa analysis for interrater reliability for an ultrasound was not calculated. The patients were evaluated only at the time of diagnosis and there was no serial imaging, which would lead us to understand the stage of disease and also in certain patients, pulmonary involvement may have appeared on the following days. LUS is an operator-dependent examination, and similar results may not be obtained by less experienced operators. However, it should be noted that basic learning of the examination technique and interpretation is a relatively simple and fast process.

5 | CONCLUSIONS

Although the manifestations of COVID-19 are milder in children, there is still concern about pulmonary involvement. Despite further prospective studies being needed to elucidate the diagnostic role of LUS in children with COVID-19, the results of the present study revealed that LUS might be a useful tool in the diagnostic steps of children with COVID-19 during the pandemic. Reduction in chest CT assessments may be possible when LUS is used in the initial diagnostic steps for these children, with chest CT being reserved for limited cases. With increased use of bedside LUS in pediatric clinics, patients can be protected from unnecessary radiation, and nosocomial spread of infections can be reduced.

ACKNOWLEDGMENT

Mina Hizal is grateful to Prof. Dr. Nural Kiper for supporting her to learn lung ultrasound.

CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

AUTHOR CONTRIBUTIONS

Mina Hizal, Yasemin Ozsurekci, and Mehmet Ceyhan contributed to the study design, analysis, interpretation of the results, and drafted the manuscript. Kubra Aykac, Gulsum I. Bayhan, Aysegul N. C. Kurt, Demet Altun, Arzu Yılmaz, Burcu C. C. Yayla, and Habip E. Akkaya contributed to data collection and interpretation of the results and revision of manuscript. Jale Karakaya contributed to data collection, analysis interpretation of the results. Mina Hizal performed lung ultrasound in all centers. Habip E. Akkaya analyzed video records of lung ultrasound and imaging findings. All authors critically revised the manuscript and approved the final version.

ORCID

Mina Hizal http://orcid.org/0000-0002-6922-4948
Kubra Aykac http://orcid.org/0000-0002-0974-4765

REFERENCES

1. Zheng F, Liao C, Fan Q, et al. Clinical characteristics of children with coronavirus disease 2019 in Hubei, China. *Curr Med Sci*. 2020;40: 275-280.
2. Li YY, Wang WN, Lei Y, et al. [Comparison of the clinical characteristics between RNA positive and negative patients clinically diagnosed with 2019 novel coronavirus pneumonia]. *Zhonghua Jie He He Hu Xi Za Zhi*. 2020;43(5):427-430.
3. Duan YN, Zhu YQ, Tang LL, Qin J. CT features of novel coronavirus pneumonia (COVID-19) in children. *Eur Radiol*. 2020;30(8):4427-4433.

4. Rubin GD, Ryerson CJ, Haramati LB, et al. The role of chest imaging in patient management during the COVID-19 pandemic: a multinational consensus statement from the Fleischner Society. *Chest*. 2020;158(1):106-116.
5. Moro F, Buonsenso D, Moruzzi MC, et al. How to perform lung ultrasound in pregnant women with suspected COVID-19. *Ultrasound Obstet Gynecol*. 2020;55(5):593-598.
6. Dong Y, Mo X, Hu Y, et al. Epidemiology of COVID-19 among children in China. *Pediatrics*. 2020;145:e20200702.
7. Xia W, Shao J, Guo Y, Peng X, Li Z, Hu D. Clinical and CT features in pediatric patients with COVID-19 infection: different points from adults. *Pediatr Pulmonol*. 2020;55(5):1169-1174.
8. Davies HD, Wang EE, Manson D, Babyn P, Shuckett B. Reliability of the chest radiograph in the diagnosis of lower respiratory infections in young children. *Pediatr Infect Dis J*. 1996;15(7):600-604.
9. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. *N Engl J Med*. 2007;357(22):2277-2284.
10. Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest*. 2008;134(1):117-125.
11. Jones BP, Tay ET, Elikashvili I, et al. Feasibility and safety of substituting lung ultrasonography for chest radiography when diagnosing pneumonia in children: a randomized controlled trial. *Chest*. 2016;150(1):131-138.
12. Smith MJ, Hayward SA, Innes SM, Miller A. Point-of-care lung ultrasound in patients with COVID-19—a narrative review. *Anaesthesia*. 2020;75(8):1096-1104.
13. Shen KL, Yang YH, Jiang RM, et al. Updated diagnosis, treatment and prevention of COVID-19 in children: experts' consensus statement (condensed version of the second edition). *World J Pediatr*. 2020;16:232-239.
14. Lanzkowsky P, Lipton J, Jonathan DF. *Lanzkowsky's Manual of Pediatric Hematology and Oncology*. 6th ed. Academic Press; 2016.
15. Salehi S, Abedi A, Balakrishnan S, Gholamrezanezhad A. Coronavirus disease 2019 (COVID-19): a systematic review of imaging findings in 919 patients. *AJR Am J Roentgenol*. 2020;215:87-93.
16. Zhou S, Wang Y, Zhu T, Xia L. CT features of coronavirus disease 2019 (COVID-19) pneumonia in 62 patients in Wuhan, China. *AJR Am J Roentgenol*. 2020;214:1287-1294.
17. Hu L, Wang C. Radiological role in the detection, diagnosis and monitoring for the coronavirus disease 2019 (COVID-19). *Eur Rev Med Pharmacol Sci*. 2020;24(8):4523-4528.
18. Hani C, Trieu NH, Saab I, et al. COVID-19 pneumonia: a review of typical CT findings and differential diagnosis. *Diagn Interv Imaging*. 2020;101(5):263-268.
19. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby JJ. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. *Am J Respir Crit Care Med*. 2011;183(3):341-347.
20. Copetti R, Cattarossi L. Ultrasound diagnosis of pneumonia in children. *Radiol Med*. 2008;113(2):190-198.
21. Stadler JAM, Andronikou S, Zar HJ. Lung ultrasound for the diagnosis of community-acquired pneumonia in children. *Pediatr Radiol*. 2017;47(11):1412-1419.
22. Tsung JW, Kessler DO, Shah VP. Prospective application of clinician-performed lung ultrasonography during the 2009 H1N1 influenza A pandemic: distinguishing viral from bacterial pneumonia. *Crit Ultrasound J*. 2012;4(1):16.
23. Altman D. Diagnostic tests. *Statistics with Confidence: Confidence Intervals and Statistical Guidelines*. BMJ book; 2000;109-110.
24. Mercaldo ND, Lau Kit F, Zhou Xiao H. Confidence intervals for predictive values with an emphasis to case–control studies. *Stat Med*. 2007;26(10)2170-2183.
25. Lomoro P, Verde F, Zerboni F, et al. COVID-19 pneumonia manifestations at the admission on chest ultrasound, radiographs, and CT: single-center study and comprehensive radiologic literature review. *Eur J Radiol Open*. 2020;7:100231.
26. Ludvigsson JF. Systematic review of COVID-19 in children shows milder cases and a better prognosis than adults. *Acta Paediatr*. 2020;109:1088-1095.
27. Musolino AM, Supino MC, Buonsenso D, et al. Lung ultrasound in children with COVID-19: preliminary findings. *Ultrasound Med Biol*. 2020;46:2094-2098.
28. Ong SWX, Tan YK, Chia PY, et al. Air, surface environmental, and personal protective equipment contamination by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) from a symptomatic patient. *JAMA*. 2020;323(16):1610-1612.
29. Buonsenso D, Pata D, Chiaretti A. COVID-19 outbreak: less stethoscope, more ultrasound. *Lancet Respir Med*. 2020;8:e27.
30. Poggiali E, Dacrema A, Bastoni D, et al. Can lung US help critical care clinicians in the early diagnosis of novel coronavirus (COVID-19) pneumonia? *Radiology*. 2020;295(3):E6.
31. Peng QY, Wang XT, Zhang LN, Chinese Critical Care Ultrasound Study Group. Findings of lung ultrasonography of novel corona virus pneumonia during the 2019-2020 epidemic. *Intensive Care Med*. 2020;46:849-850.
32. Denina M, Scolfaro C, Silvestro E, et al. Lung ultrasound in children with COVID-19. *Pediatrics*. 2020;146:e20201157.
33. Lu X, Zhang L, Du H, et al. SARS-CoV-2 infection in children. *N Engl J Med*. 2020;382:1663-1665.
34. Yang P, Liu P, Li D, Zhao D. Corona virus disease 2019, a growing threat to children? *J Infect*. 2020;80:671-693.

How to cite this article: Hizal M, Aykac K, Yayla BCC, et al. Diagnostic value of lung ultrasonography in children with COVID-19. *Pediatric Pulmonology*. 2021;56:1018–1025. https://doi.org/10.1002/ppul.25127