Accuracy of chest ultrasonography in the diagnosis of coronavirus disease 2019 pneumonia

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Background
Coronavirus disease 2019 (COVID-19) virus infection is an ongoing, catastrophic, worldwide pandemic with significant morbidity and mortality. Large numbers of people who are getting COVID-19 virus infection are at high risk of developing COVID-19 pneumonia; early diagnosis of COVID-19 pneumonia, patient care, and isolation using simple, less expensive images are required. High-resolution computed tomography chest (HRCT chest) is the reference standard method for the diagnosis of COVID-19 pneumonia; however, it is expensive with increasing the exposure risk; chest ultrasonography (CUS) may be an alternative method.
Patients and methods
CUS is performed on patients accepting to participate in the study at presentation of COVID-19 suspicious cases. HRCT chest to confirm COVID-19 pneumonia were done within 24 h of CUS examination. Two chest consultants who are experts in CUS at Assiut University Hospital performed CUS. The CUS is done using a convex probe of 3.5 MHz. The CUS was considered positive for pneumonia if the examiners find the presence of abnormal multiple vertical B lines with or without the presence of consolidation dots unilateral or bilateral with good cardiac function; HRCT chest results are recorded.
Results
In all, 197 patients were included in the study (102 males, mean age 48 ± 16.2 years). Regarding comorbidity: 10% had diabetes mellitus and 9% had hypertension. Ten (5%) patients needed hospitalization with a mean oxygen saturation of 95 ± 5%. One hundred fifty-two patients confirmed COVID-19 pneumonia with HRCT chest, while 45 patients had normal HRCT chest. CUS showed positive pneumonic finding in 128 patients and normal picture in 69 patients. There was good association (r=0.690, P<0.001) between both diagnostic modalities in COVID-19 pneumonia diagnosis. Sensitivity and specificity and accuracy of CUS in the diagnosis of COVID-19 pneumonia were 84.56, 95.83, and 87.31%, respectively, when compared with HRCT chest. One hundred and two patients were successfully followed; all of them showing clinical and ultrasonographic improvement.

Keywords:
chest ultrasonography, computed tomography, coronavirus disease 2019 pneumonia

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Introduction

Coronavirus disease 2019 (COVID-19) disease is an emerging pandemic caused by SARS-CoV-2 virus starting in late 2019 [1]; from this time till now there is widespread infection throughout the world with significant morbidity and mortality [2]. COVID-19 pneumonia is highly common and the leading cause of major morbidity and death in infected patients [3,4]. There is medical acceptance of diagnosing COVID-19 pneumonia with high-resolution computed tomography (HRCT) chest as the reference standard with positive SARS-CoV-2 virus RT-PCR test; in some cases still COVID-19 pneumonia be diagnosed with negative RT-PCR if clinically and radiologically suspected [5]. HRCT is expensive; exposed the radiological team to the infection; and exhaust the patients, radiological team, and devices with high incidence of the disease [6]. Follow up of patients with consecutive HRCT chest is commonly not preferable within short time. Chest ultrasound (CUS) is an easy, promising diagnostic method that could identify pneumonia with high accuracy [7]. CUS use might be extended to diagnose COVID-19 pneumonia at the bedside [8] with options to follow up patients easily. With pandemic in the outpatient setting, it is important to assess patients rapidly using the most affordable diagnostic imaging approach. CUS has the advantages of low cost, no ionizing radiation, availability, and

less patient exposure to the community; however, the accuracy of CUS in the diagnosis and follow-up of COVID-19 pneumonia patients is still under study. Our aim is to determine the feasibility and accuracy of CUS in the diagnosis of COVID-19 pneumonia in comparison with chest CT, evaluate the value of CUS in the follow-up of COVID-19 pneumonia patients, and to display the ultrasonography COVID-19 pneumonia signs observed in this cohort study.

Patients and methods

This is a prospective comparative study, conducted in Assiut Governorate from May 2020 to June 2021. The statement has been taken from Faculty of Medicine, Assiut University, Assiut, Egypt. Assiut University ethics committee has approved the study (IRB number: 17300594). During this period, the patients who attended the pulmonology clinic for consultant's opinion for suspicious COVID-19 pneumonia management during the outbreak were asked to participate in the present study. After a brief history taking and clinical examination by the attending pulmonologist, the patients who arranged to get CT chest were asked to participate in the study. The included patients had CUS with a pulmonologist, who was blinded to chest CT results; the CUS was done using a convex probe of 3.5 MHz. CUS were done by expert consultants (M.K.A., M.N.M. with 10 years' experience; all the precautions were taken to avoid the spread of infection (all patients were wearing face masks, the operators had their personal protective equipment, PPE, and the clinic was well ventilated. During the procedure, all chest anatomical CUS planes are looked for any findings that help in the diagnosis and were recorded [6]. CUS findings include pleural findings, pleural effusion, pleural sliding, pleural thickening, and pleural interruptions [9]; parenchymal findings such as consolidations, vertical B lines (hyperechoic vertical artifact rays that arise from the pleural line and extend vertically to the end of the screen with synchronous motion with pleural sliding), and its related artifacts as confluent artifacts, light beam artifacts (brown ring) [10], horizontal A lines (horizontal lines with a regular vertical spacing down the image) either normal profile or abnormally increased and echogenic lesions (hypoechoic, hyperechoic, anechoic), rapid visual cardiac size, and functions were done [11]. The CUS considered positive for COVID-19 pneumonia if the examiners find the presence of abnormal vertical B lines with or without the presence of consolidation dots unilateral or bilateral with good visual cardiac function. Follow up of patients with CUS was done within 3 weeks from the first visit for determination of the resolution of abnormal sonographic artifacts. HRCT results were recorded and considered COVID-19 pneumonia positive if the radiologists reported the diagnosis CORAD 2 or more [12]. The patients final diagnoses were obtained from the record sheet of patients.

Statistical analysis

The statistical analysis was performed using SPSS (version 20.0; SPSS Inc., Chicago, Illinois, USA). Continuous variables were presented as means±SD and categorical variables were presented as percentages. Spearman test was used to correlate variables between groups. Receiver operating characteristic analysis was used to draw the sensitivity, specificity, and accuracy of CUS in comparison with HRCT. MedCalc statistical internet-based software was used to calculate CUS sensitivity specificity and accuracy in COVID-19 pneumonia. A P value less than 0.05 was considered statistically significant.

Result

In all, 197 patients were included in the study, with a mean age of 48 ± 16.2 years; 52% were males; 10% had diabetes mellitus; 9% had hypertension; 5% needed hospitalization; and the mean oxygen saturation was 95 ± 5%; 152 patients were confirmed to have COVID pneumonia with HRCT chest while 45 patients had normal HRCT chest. CUS was positive for pneumonia in 128 patients while normal CUS in 69 patients. CUS is having good association (r=0.690; P<0.001) when correlated with HRCT to diagnose COVID-19 pneumonia. Sensitivity and specificity and accuracy of CUS in the diagnosis of COVID-19 pneumonia are 82.89, 95.56, and 85.79%, respectively, when compared with HRCT chest.

Follow-up chest ultrasonography

One hundred and two patients were successfully followed up by CUS for the resolution of abnormal ultrasonography artifact signs; all of them were followed up within 3 weeks. They all showed some ultrasonographic improvement; 28 (27.5%) patients were showing persistence of some ultrasonographic signs after 3 weeks, 74 (72.5%) patients showed complete resolutions of the abnormal CUS artifact signs and return to the normal pattern. Strong negative associations were found between oxygen saturation and persistence of abnormal sonographic artifacts (−0.786, P<0.001), and also positive association between persistence of prolonged persistence of abnormal ultrasonography artifacts and age of the patients (0.528, P<0.001). Four patients of the normal CUS in the first check (early presentation) developed abnormal B vertical lines within 10 days from the first visit; all of them showed complete CUS resolution within 3 weeks after appearance of CUS signs. Ten (5%) patients were

Table 1 Baseline patient characteristics

Variables	Mean±SD/*n* (%)
Age	48.6±16.2
Male	102 (51.7)
Diabetes mellitus	19 (9.6)
Hypertension	18 (9.1)
Smokers	19 (9.6)
Anosmia	17 (8.6)
Fever	136 (69)
Dyspnea	120 (60.9)
Cough	144 (73)
SpO_2%	95±5
Hospitalization	10 (5.1)

Table 2 Chest ultrasonography patterns

Ultrasonographic signs	*n* (%)
Vertical B lines separate	128 (64.9)
Confluent vertical artifacts	35 (17.8)
Brown ring artifacts (light beam)	50 (25.4)
Small peripheral subpleural hypoechoic artifacts	13 (6.6)
Pleural effusion	3 (1.5)
Consolidations	4 (2)
Thickened or irregular pleura	128 (64.9)

Table 3 High-resolution chest computed tomography patterns

HRCT chest signs	*n* (%)
Normal	45 (22.8)
Patch ground glasses	126 (63.9)
Diffuse ground glass	8 (4.1)
Ground glass with consolidation area	18 (9.1)

HRCT, high-resolution computed tomography.

Table 4 Chest ultrasonography accuracy in the diagnosis of coronavirus disease 2019 pneumonia in comparison with high-resolution computed tomography chest

	Value (%)	95% CI
CUS sensitivity	82.89	75.95–88.51
CUS specificity	95.56	84.85–99.46
CUS positive predictive value	98.44	94.19–99.59
CUS negative predictive value	62.32	53.68–70.24
CUS accuracy	85.79	80.12–90.34

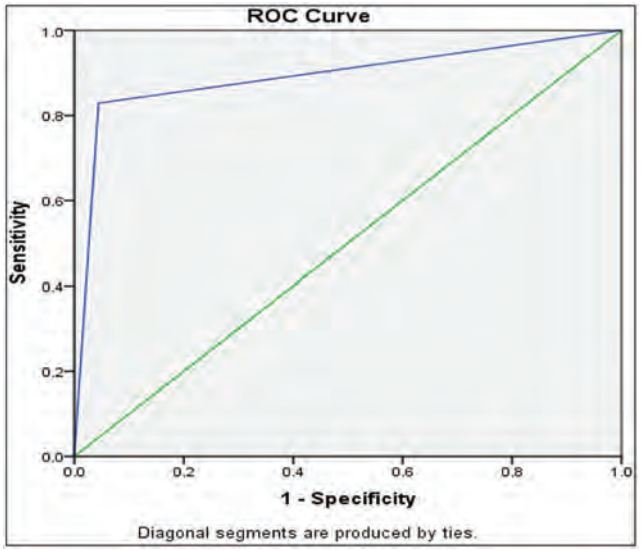
CI, confidence interval; CUS, chest ultrasonography.

hospitalized for their need to oxygen therapy. Three patients had minimal pleural effusion with CUS with confluent diffuse vertical artifacts all over the chest examination regions; the three patients had to be hospitalized; unfortunately, two of them deceased, and one is having post-COVID respiratory disability after discharging from the hospital (Tables 1–4).

Discussion

Infectious interstitial pneumonia could be identified with CUS and has characteristic CUS artifacts, which lead the physicians to the diagnosis [13]. These artifacts represent an increase of lung interstitial water on the expense of alveolar air with raised lung density [10]. COVID-19 pneumonia is acute interstitial pneumonia caused by SARS-CoV-2 virus, predominantly affecting the peripheral lung areas with patch distribution at start that might infiltrate diffusely accordingly, which give good chance to be recognized with CUS [14]. As SARS-CoV-2 infection reaches the lung parenchyma a cascade of inflammatory processes occur with recruiting lymphocyte and macrophage cells with increasing the amount of lung fluid, especially in the alveolar septa [15], increasing the lung interstitial water predominantly peripherally making it ultrasonographically visible. Although CUS findings in COVID-19 pneumonia are not pathognomonic to the disease and can be identified with many interstitial conditions [13,16], in certain clinical circumstances it might be significantly useful. This is also considered similar to chest computed tomography imaging findings [17]. The presence of typical interstitial pneumonia CUS signs during the surge of SARS-CoV-2 in previously healthy individuals should be considered for COVID-19 pneumonia as also noted by Volpicelli *et al.* [18]. The present study shows CUS as an important image in COVID-19 pneumonia management with good sensitivity when compared with HRCT chest (Fig. 1). In addition, it could ensure the absence of COVID-19 pneumonia with accuracy in most of our cohort; this is also noted with Lieveld *et al.* [19] as they observed the interesting comparability between both images. The patients with false-negative CUS image in our cohort were usually mild disease and rapid recovery mostly happens. None of the severe or moderately severe infection cases was having negative CUS; in contrary,

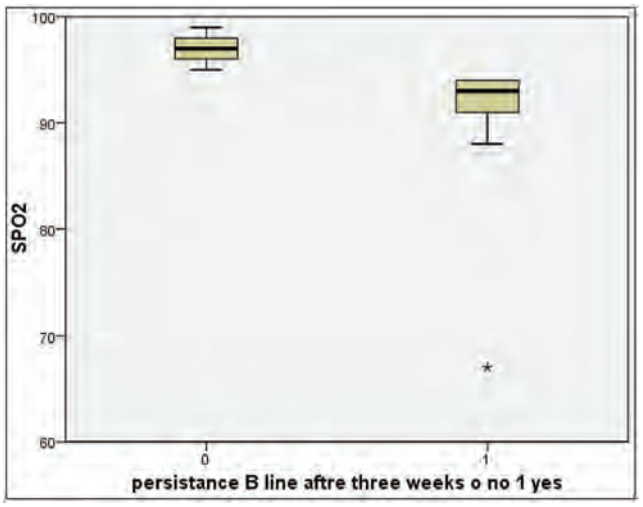
Figure 1



ROC curve showing CUS sensitivity and specificity to HRCT chest in the diagnosis of COVID-19 pneumonia. COVID-19, coronavirus disease 2019; HRCT, high-resolution computed tomography; ROC, receiver operating characteristic.

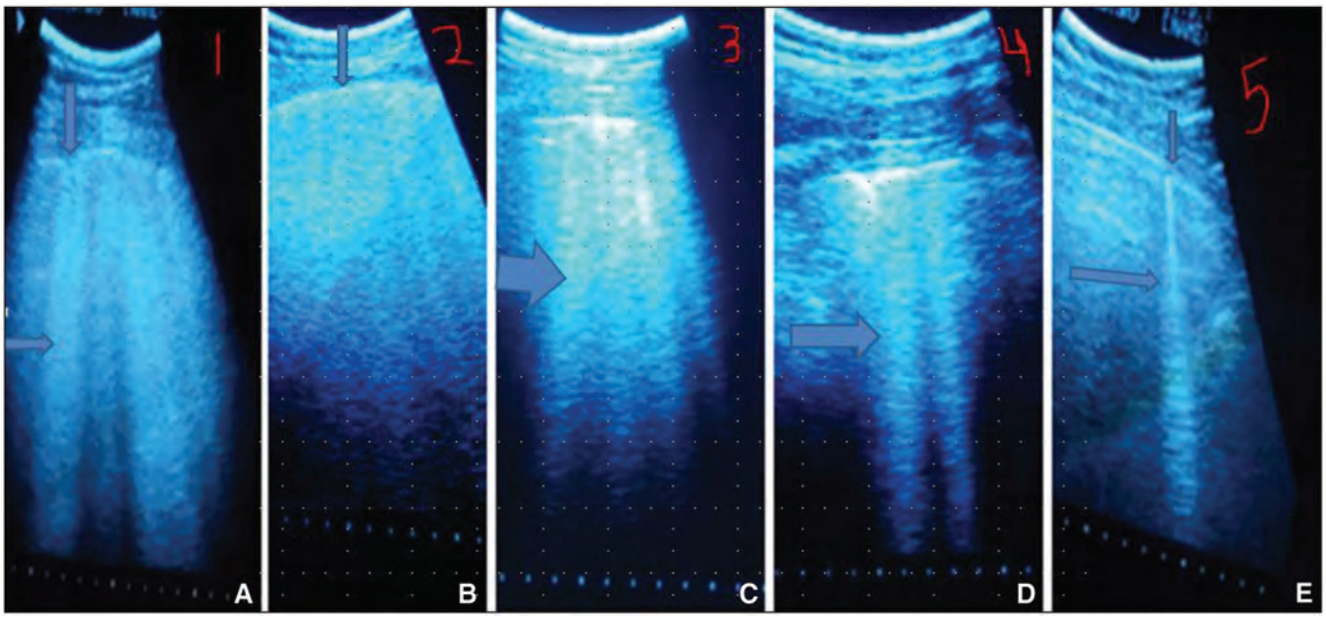
they were having significant CUS finding which alerts the sonographers about the severity of the condition, especially if the CUS abnormal artifacts present in most of the examined regions of the lung. These results promote dealing with CUS as a decision management tool. These findings are also recorded with other authors as the severity of COVID-19 pneumonia is associated with CUS findings [12,18]. The specificity determined in our study is higher than observed by other authors, which might be explained by the use of HRCT chest as a reference standard for diagnosis and not for molecular diagnosis [20]. The clear ultrasonography artifacts such as comet tail, brown ring, peripheral dot consolidation, and confluent vertical artifacts with or without normal lung pattern between abnormal artifacts according to the severity can be recognized easily giving the physician the confidence to diagnose interstitial pneumonia as COVID-19 pneumonia especially during the outbreak [14], Fig. 3 shows the most common CUS artifacts that were noted in our study. These artifacts could be present separately or collectively in the same patient or lung regions according to the extent of the disease. These results give the patient the advantages of rapid bedside diagnosis and might provide prognostic idea regarding his condition. Three of our patients had minimal pleural effusion; all of them necessitate urgent hospitalization and later on ICU admission, two unfortunately passed away and the third one was discharged from the hospital with moderate respiratory disability. We were recognizing in our study that patients with confluent B lines appearing in most lung regions commonly have low oxygenation and need hospitalization; the less the appearance of B lines the less the severity of the disease. We noted that there are significant associations between oxygenation with pulse oximetry with the persistence of B line for a longer duration (Fig. 2). Many CUS signs are characteristic to diagnose interstitial pneumonia including COVID-19 pneumonia as observed in the present study. Abnormal vertical B-line patterns, with thickened interrupted pleural line is a common

Figure 2



Association between persistence of vertical lines at 3 weeks and patient oxygen saturation at presentation.

Figure 3



CUS patterns of COVID-19 pneumonia of five patients noted in our cohort. Image (a): irregularly interrupted pleural line with small hypoechoic lesions and diffuse confluent vertical B lines; image (b) thickened diffuse pleural lines with diffuse, confluent vertical lines commonly noted in severe COVID-19 pneumonia cases (granular appearance); image (c): multiple vertical lines with thickened irregular corresponding pleura; image (d): two brown ring artifacts (light beam) commonly noted in mild and moderate cases; image (e): single light beam artifact with slight hypoechoic lesions at its pleural base. COVID-19, coronavirus disease 2019.

finding; brown ring artifact is a predominant feature in these cases, a less common finding is the subpleural hypoechoic small artifacts, an unusual finding is clear consolidation dots; a rare finding is the presence of minimal effusions that are detected in severe cases (Fig. 3). Some of these findings are noted to carry a prognostic risk as the presence of pleural effusion or confluent diffuse vertical artifacts as per our interpretations [20]. It is not uncommon to find most of the characteristic artifacts together especially in severe cases; however, mild cases commonly show vertical B lines or may show normal CUS especially if the COVID-19 pneumonia patch is present away from the periphery. Our study explores CUS findings in COVID-19 pneumonia and determine the accuracy of CUS in COVID-19 pneumonia diagnosis that facilitate patient diagnosis and to rapidly start treatment, besides determining the feasibility of CUS in the patient follow-up. CUS has the ability to follow up the patients frequently with accuracy and decreasing the risk of frequent exposure to ionizing radiation images. Now with starting to return to normal life with opening the shutdown in most world countries and also the medical institute, making the need for the imaging tool to help recognize COVID-19 pneumonia is mandatory; CUS might be the preferred image when considered in relation to other images [21].

The limitations of our study are not all patients had RT-PCR for SARS-CoV-2 virus detection due to shortage of the test availability and cost; however, in clinical practice not all patients with COVID-19 pneumonia have a positive RT-PCR test as the test sensitivity is around 70% and its diagnosis in this case depends on the clinical scenario and imaging [22].

We like to notify that part of this study is presented as poster abstract at the 2021 American Thoracic Society virtual conference.

Conclusion

CUS is a promising and interesting method for the diagnosis of COVID-19 pneumonia with high accuracy when compared with HRCT chest and may be considered in COVID-19 pneumonia management.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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