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REVIEW

The Point-of-Care Ultrasound (POCUS) by the Handheld Ultrasound Devices (HUDs) in the COVID-19 Scenario: a Review of the Literature

Antonio Martocchia[1] · Enrico Bentivegna[1] · Daniela Sergi[2] · Michelangelo Luciani[1] · Michela Barlattani[3] · Michele Fortunato Notarangelo[1] · Cinzia Piccoli[1] · Giorgio Sesti[3] · Paolo Martelletti[1]

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Abstract
The use of portable ultrasound (US) devices is increasing, due to its accessibility, versatility, non-invasiveness, and its significant support in the patient management, extending the traditional physical examination through the POCUS (point-of-care ultrasound). The pocket-size or handheld ultrasound devices (HUDs) can easily perform focused exams, not aiming to substitute for the high-end US systems (gold standard), since the HUDs usually have more limited functions. The HUDs are promising tools for the diagnosis, prognosis, and monitoring of the COVID-19 infection and its related disorders. In conclusion, the routine use of HUDs may ameliorate the management of COVID-19 pandemic, according to the guidelines for the POCUS approach and the procedures for the protection of the patients and the professionals.

Keywords Portable ultrasound · Point-of-Care ultrasound · COVID-19 · Echoscopy

Introduction

Evidence in the literature has recently increased about the extending use of the so-called POCUS (point-of-care ultrasound) by portable US devices, improving the timely medical decision-making process, in all the different acute patients' settings, outside (as at home and/or in ambulance) or inside the healthcare facilities and hospitals (as in emergency rooms and wards) [1–24].

Since its appearance in 2019, the COrona VIrus Disease 19 (COVID-19) infection required major efforts to protect the patients, because of the high risk of mortality, particularly in comorbidity (as in elderly people) and in not protected subjects [25–29]. The advantages of the expanding use of POCUS in the COVID-19 pandemic scenario may involve the resuscitative (related to an acute resuscitation), the diagnostic (enabling the early diagnosis and implementing the diagnostic capacity), the symptom/sign-based (used in a specific clinical pathway), the procedure guidance (guiding a specific medical procedure), and the therapeutic/monitoring activities (monitoring the follow-up of diseases and therapies) [30]. At the same time, the US examination should integrate the clinical physical examination with high-impact images, without replacing it.

A miniaturized hand-held US scanner was developed as early as 1978, with a limited imaging performance and a weight of about 1.5 kg [31, 32]. Nowadays, technological advances have led to small devices, no larger than a mobile phone (referred to as pocket-size or handheld ultrasound devices, HUD), which can be easily used to perform partial, focused exams, not aiming to substitute for the high-end US systems (gold standard).

As matter of fact, the high-end US systems have the full range of standard echo modalities and measurements: mono-dimensional or M-mode (MM); two-dimensional (2-D) or bi-dimensional (B-mode); three-dimensional (3D); color Doppler (Color); continuous Doppler (CW); pulsed wave Doppler (PW); tissue velocity imaging (TVI); transesophageal modality (TEE); and contrast echo (Contrast) modality. The HUDs usually have more limited functions, such as

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✉ Antonio Martocchia
antonio.martocchia@uniroma1.it

1 Emergency Medicine Unit, S. Andrea Hospital, Sapienza University of Rome, Via Di Grottarossa 1035, 00189 Rome, Italy

2 Radiology Unit, S. Andrea Hospital, Sapienza University of Rome, Rome, Italy

3 Internal Medicine Unit, S. Andrea Hospital, Sapienza University of Rome, Rome, Italy

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MM, 2D, Color, PW, measurement packages, and imaging optimization (SonoCT real-time compound, XRES adaptive, Tissue Harmonic Imaging) [33–40]. Many HUDs have an included display, such as Vscan and Vscan Extend (GE), C Scan and Optigo (Philips), Acuson (Siemens), iViz and NanoMaxx and iLook (Sonosite), uSmart (Terason) and Sonimage (Konica Minolta), and EvoTouch (Quantel Medical). Other HUD beam images to tablet/smartphone are Vscan Air (GE), Lumify (Philips), Sonoeye (Chison), Butterfly (iQ), Clarius (Clarius Mobile Health), SonoQue C4PL (Sonoque), and Cerbero.3 (ATL).

Methods

The Study USinMED was approved on the role of the bedside ultrasound in our Hospital, by the Ethical Committee of Sapienza University of Rome (RIF. CE 6583_2021).

We searched online medical literature database (PubMed) from 2019 to 2022, covering the 3-year period that marked the COVID-19 appearance and pandemic diffusion, using the search strategy to address the following: (1) problem (COVID-19 disease); (2) intervention (hand-held or portable US); comparisons (POCUS versus conventional imaging); (3) outcome (accuracy); (4) article type (experimental studies); and (5) study design (any).

The following string was used in searching the PubMed database: (hand held ultrasound [Title/Abstract] OR portable ultrasound [Title/Abstract] AND point of care ultrasound [Title/Abstract] AND COVID-19 [Title/Abstract].

Our predetermined list of exclusions included the following: non-English study; impossible to obtain the full-text; article type (e.g., opinion of experts, editorials, tutorials, case reports, abstract, commentary, book chapters, reviews or systematic reviews); no comparison of hand-held US with other imaging method (e.g., X-ray, conventional US, computed tomography; magnetic resonance imaging); US not performed in adult (study in child); US performed by non-doctor (e.g., medical student, nurse); and study not applied to human subject (veterinary study).

The articles' selection involved a two-step screening process by two independent researchers: in the first step, the studies were screened for relevancy to hand-held US in COVID-19, and, in the second step, the full texts were screened for inclusion. Any disagreement was resolved by the intervention of a third independent reviewer, if necessary.

Results

We retrieved n.334 articles, and 5 studies were evaluated (Fig. 1; Table 1) [41–45]. We initially excluded n.2 books, n.6 systematic reviews and meta-analyses, n.38 reviews, n.23 case reports, n.39 studies in child, n.21 studies in other animals, n.9 tutorials, and n.1 editorial. Then, we excluded n.166 studies not related to COVID-19, n.19 papers not related to US, n.2 studies with not available full text, n.2 no comparison with other imaging method, and n.2 not specified US devices.

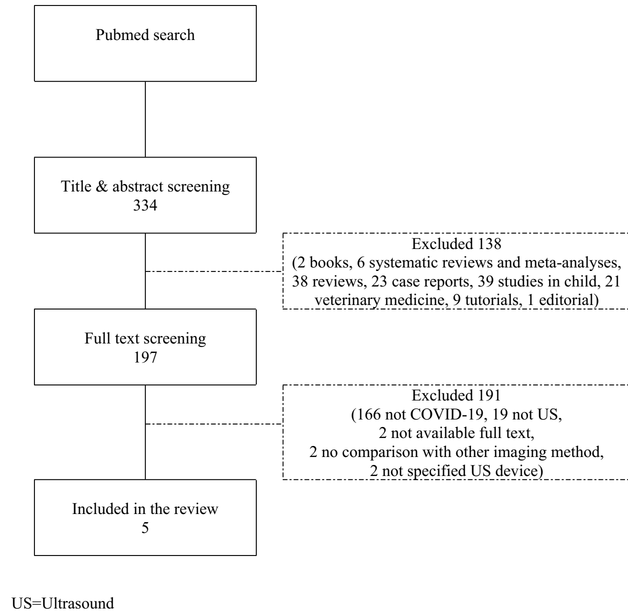

Fig. 1 Flowchart of the literature screening

Falgarone et al. evaluated n.50 inpatients by lung US (LUS) to predict lung damage at CT scan and oxygen requirement: US was 89% sensitive and 100% specific in predicting CT chest scan abnormalities and 95% sensitive and 67% specific in detecting oxygen requirements [41].

Jalil et al. studied n.69 patients within the first 24 h of hospitalization by LUS for the evaluation of various acute pathologies: a high sensitivity (91%) and specificity (86%) were reported for COVID-19 pneumonia [42].

Gibbons et al. examined n.110 subjects of an urban university emergency department to compare LUS and chest X-ray for detecting viral/atypical pneumonia (CT scan gold standard): LUS sensitivity and specificity were 98% and 33% (versus 70% and 44% for chest X-ray) [43].

Abd Wahab et al. recruited n.261 subjects in out-of-hospital setting, and subsequently, chest X-rays were taken after being admitted to the healthcare facilities: LUS detected pulmonary changes in more subjects than X-ray (97% versus 45%) among subjects with normal LUS but reported abnormal chest X-ray; only 1 subject had pulmonary infiltrate changes (there was no agreement as the Cohen's kappa coefficient was 0.08) [44].

Dadon et al. evaluated n.103 patients within 48 h of admission to the hospital by echocardiogram and LUS evaluation: a substantial agreement (kappa = 0.612, $p < 0.001$)

Table 1 Characteristics of the reviewed studies

Study, year [Ref.]	Location	Sign or disease/organ	Device	Comparator test
Falgarone et al., 2020 [41]	Paris, Marseille/France	Pneumonia/lung	EvoTouch Quantel Medical	CT scan
Jalilet al., 2020 [42]	Waxahachie/TX, USA	Pneumonia/lung	Vscan ExtendGE	Chest X-ray (8% CT scan)
Gibbonset al., 2021 [43]	Philadelphia/PA, USA	Pneumonia/lung	Butterfly iQ	Chest X-ray, CT scan
Abd Wahab et al., 2022 [44]	Kuala Lumpur, Selangor Darul Ehsan, Kelantan/ Malaysia	Pneumonia/lung	Lumify Philips,BenQ T3300	Chest X-ray
Dadon et al., 2022 [45]	Jerusalem/Israel	Cardiovascular disease, pneumonia/heart, lung	Vscan ExtendGE	Chest X-ray

CT computed tomography

was demonstrated between the operator and the echocardiographer for left ventricular ejection fraction (LVEF); chest X-ray demonstrated lung infiltrates in 74% of cases [45].

Discussion

The technical characteristics of HUDs allow to evaluate the main aspects of the heart, lungs, and/or abdominal organs, and they are very useful in patients with a significant comorbidity and polypharmacy (respectively, an average of 7 diseases and 8 drugs) [25, 46]. Previous studies in the literature focused to the left/right ventricular functions, valve regurgitation (by Color option), B-line for lung score, intracavitary (pleural, pericardial, intra-abdominal) effusions, inferior vena cava collapsibility, biliary/urinary tract disorders, aortic diameters, and deep vein thrombosis [23, 35, 47–57]. We proposed three main reports for the echoscopy in Figs. 2, 3, 4, and 5.

The HUDs may be widely used by general medicine practitioners, emergency medicine specialists, internists, geriatricians, and students in teaching schools, with proper training and education of users [36, 58–65]. A tailored training program model for HUD users was proposed for echocardiography: an in-hospital period of 60 days (3 days per week) with visual assessment of at least 150 exams [66]. For emergency US, the trainees should complete a benchmark of 150–300 total exams depending on the number of applications being utilized, as suggested by the American College of Emergency Physicians [23].

The US studies on COVID-19 evaluated by this review were conducted in out-of-hospital [42] and in-hospital settings, and, in particular, in the emergency department [43], in designated medical wards [45], in the department of infectious diseases [41], and within the first 24 h of hospitalization [42]. In lung US protocol, the patients were examined, respectively: in the supine position, with 4 bilateral scanning areas (3 anterior upper, mid, and lower lung zones and the posterolateral costophrenic recess on each hemi thorax) [42]; sitting position with 12 windows (anterior superior, anterior inferior, lateral superior, lateral inferior, posterior superior and posterior inferior bilateral window) and a lung score ranged from 0 to 36 (0 = none, 1–7 = mild; 8–18 = moderate, and 19–36 = severe score) [44, 45] or sitting position with 8 windows (bilaterally anterior upper and middle, posterior middle and lower lobe) [42]; and not limited position (lying, sitting and standing), with 6 locations for each hemithorax (2 anterior, 3 side, and 1 posterior location) [41].

The studies showed high sensitivity (91–95%) and lower specificity (33–100%) for identifying COVID-19 disease by using lung POCUS by HUDs [41–44].

Gibbons et al. pointed out that congestive heart failure (CHF) and interstitial lung disease (ILD) have similar findings as COVID-19 pneumonia on LUS (with three or more B-lines or the presence of a single confluent B-line encompassing a third or more of the visualized intercostal space) [43]. The analysis of the different lung regions may increase the specificity of the test.

Examining the evidence in the literature, a quick guide recently proposed a 12-point lung exam (6 points on each lung), in order to increase the sensitivity in the detection of COVID-19 findings [67], whereas other studies suggested the 6 or 10 point exam [68–70].

As described in the literature, US has highest levels of sensitivity and specificity comparable to CT with regard to the detection of pleural (respectively range 92–100% and 93–100%, US versus CT), pericardial (range 87–94% and 92–96%), and intra-abdominal (range 73–76% and 97–98%) effusions [71–74].

Two studies reported that the ultrasound examination was performed within 1–5 days from symptom/admission [42, 45]. The detectable extent of the lung lesions may be related to the time elapsed before the US examination and may increase the sensitivity of the test.

The severity of the COVID-19 infection is related to the development of a severe pulmonary insufficiency and complications, like superinfections, coagulation disorders (deep vein thrombosis, pulmonary embolism), cardiovascular

Fig. 2 Bedside heart echoscopy report

Surname, name: Weight (kg): Height (cm):
Date: SBP/DBP (mmHg): HR (beats/min):

PLAx view			
RV wall thickness (mm):	(nv 1-5)	RV diameter (mm):	(nv 7-26)
Aorta (valve anulus) (mm):	(nv 21-35)	Maximal ascending aorta (mm):	(nv <35)
Apertura cuspidi (mm):	(nv 15-27)	LA ap diameter (mm):	(nv 20-40)
IVS thickness (mm).	(nv 6-11)	PW thickness (mm):	(nv 6-11)
LV TD diameter (mm):	(nv 36-56)	LV TS diameter (mm):	(nv 25-41)
PSAx view			
Pulmonary trunk diameter (mm):	(nv <29)		
4C view			
LV TD t diameter (mm):		LV TS t diameter (mm):	
LV TD l diameter (mm):		LV TS l diameter (mm):	
LA t diameter (mm):		LA l diameter (mm):	
RV TD basal diameter (mm):	(nv 27-41)	RV mid-cavitary diameter (mm):	(nv 19-35)
RA t diameter (mm):		RA l diameter (mm):	
TAPSE (mm):	(nv >16)	RV thickness (mm):	(nv <5)
2C view			
LA t diameter (mm):		LA l diameter (mm):	
Valvular (Ao, M, T, P) abnormality (stenosis/regurgitation):			
SC view			
IVC diameter exp (mm):	(nv <21)	Collapsibility with insp (%):	(nv >50)

The sonographer may report the linear cardiac measurements in this template.
The aortic annulus should be measured at peak mid-systole (in contrast to the other dimensions, which are measured at end-diastole), from inner edge to inner edge.
SBP/DBP=systolic/diastolic blood pressure, HR=heart rate, PLAx=parasternal long axis view, PSAx=parasternal short axis view, 4C=four chamber view, 2C=two chamber view, RV=right ventricle, nv=normal values, LA=left atrium, LV=left ventricle, IVS=inter ventricular septum, PW=posterior wall, TD=telediastolic, TS=telesystolic,
ap=antero-posterior, t=transverse, l=longitudinal, Ao=Aortic, M=mitral, T=tricuspidal, P=pulmonary valve, SC=subcostal view, IVC=inferior vena cava.

Fig. 3 Derived heart echoscopy measurements

BSA			
FS (%):	(nv 27-42)	RWT:	(nv ≤0.42)
LA area (cmq):	(nv <20)	LA area i (cmq/mq):	(nv <14)
LA vol (ml):	(nv <53)	LA vol i (cmq/mq):	(nv <29)
LV TD vol (ml):	(nv 67-155 M, 56-104 F)	LV TS vol (ml):	(nv 22-58 M, 19-49 F)
LV TD vol i (ml/mq):	(nv <80)	LV TS vol i (ml/mq):	(nv <40)
EF (%) (cubic/Teich/Quin):	(nv >50)	Stroke vol (ml):	(nv 60-100)
LV mass (g):	(nv <215 M, <162 F)	LV mass i (g/mq):	(nv <115 M, <95 F)

The sonographer may calculate and report the derived cardiac measurements in this template.
BSA=body surface area, FS=fractional shortening, RWT=relative wall thickness, EF=ejection fraction, i=index, vol=volume, Teich=Teichholz method, Quin=Quinones method.
Du Bois: BSA = 0.007184 x weight$^{0.425}$ x height$^{0.725}$
FS=LV TD diameter – LV TS diameter/LV TD diameter, RWT=2PW/LV TD diameter
LA volume= 8/3π x (LA area in 4C x LA area in 2C/LA minor Long diameter)
LV Mass (g) =0.8{1.04[([LVEDD + IVSd +PWd]^3 - LVEDD^3)]} + 0.6
LV TD volume cubic method= LV TD diameter^3
LV TD volume Teichholz method= 7/(2.4 + LV TD diameter in PLAx) x LV TD diameter^3 in PLAx
LV TD volume Quinones method= π/6 x LV TD diameter^2 in 4C x LV Long diameter in 4C
LV TS volume cubic method= LV TS diameter^3
LV TS volume Teichholz method= 7/(2.4 + LV TS diameter in PLAx) x LV TS diameter^3 in PLAx
LV TS volume Quinones method= π/6 x LV TS diameter in 4C^2 x LV Long diameter in 4C

diseases (myocarditis, pericarditis, atrial fibrillation and/or acute hearth failure, Takotsubo cardiomyopathy, shock), cytokine release syndrome, acute kidney and liver injury, and brain damage [25, 75]. The HUDs are promising tools for the diagnosis, prognosis, and monitoring of COVID-19-related disorders, and POCUS is increasingly being used,

Fig. 4 Bedside lung echoscopy report

Surname, name: Weight (kg): Height (cm):
Date:

RR (breaths/min): SpO_2:
O_2 supplementation (yes/no): LFNC (l/min): HFNC (l/min): VMK (%, l/min):
NIV (yes/no): BiPAP: CPAP: Helmet:
Setting/pattern: PEEP (cmH_2O): Ppeak (cmH_2O): Pplat (cmH_2O):
RR (breaths/min): I:E ratio: V_T (ml/kg): FIO_2 (%):
BGA: pH: pO_2 (mmHg): pCO_2 (mmHg): HCO_3- (mEq/l): BE (mEq/l): SaO_2 (%):

SpO2=pulse oxygen saturation, BGA=blood gas analysis, PaO2=partial pressure of arterial oxygen, PaCO2=partial pressure of arterial carbon dioxide, HCO3-=concentration of arterial bicarbonate, BE=relative excess of base, SaO2=arterial oxygen saturation, LFNC=low-flow nasal cannula, HFNC=high-flow nasal cannula, VMK=Ventimask, NIV=non-invasive mechanical ventilation, BiPAP=bilevel positive airway pressure, CPAP=continuous positive airway pressure, RR=respiratory rate, PEEP=positive end-expiratory pressure, Ppeak=peak pressure, Pplat=plateau pressure, I:E ratio=inspiratory:expiratory ratio, VT=tidal volume, FIO2=fraction of inspired oxygen.

	LUS					
	Right lung			Left lung		
Fourth Rib	RPS:	RLS:	RAS:	LAS:	LLS:	LPS:
	RPI:	RLI:	RAI:	LAI:	LLI:	LPI:
		RPAL	RAAL		LAAL	LPAL

The sonographer may report the lung ultrasound score in this template.
The right and left fourth rib respectively separates the superior and inferior regions of right and left lungs, the right posterior and anterior axillary line (RPAL and RAAL) and the left posterior and anterior axillary line (LAPL and LAAL) respectively separate the anterior, lateral and posterior regions of lungs. LUS=lung ultrasound score (value 0-36; 0=A-patten, 1=B-pattern >3/filed, 2=B-pattern crowded +/- subpleural consolidations, 3=consolidation), E=effusion, Pn=pneumothorax, NS=sliding abolition, LP=lung pulse, RPS/RLS/RAS= right posterior/lateral/anterior superior lung, RPI/PLI/RAI=right posterior/lateral/ anterior inferior lung, LPS/LLS/LAS=left posterior/lateral/ anterior superior lung, LPI/LLI/LAI=left posterior/ lateral/anterior inferior lung.

as recently reported [68, 76–84]. The heart and the lung are the most investigated sites by US in COVID-9 patients, with particular attention to the left/right systolic function, valvular pathology, inferior vena cava collapsibility, intracavitary effusions, lung B-lines, and subpleural consolidations/lung hepatization (for the lung score) [69, 75, 81–83, 85–89].

In the study of Falgarone et al. [41], the authors demonstrated that the lung US was a good screening test for oxygen requirements (≥ 0.5 l/min), with 95% sensitivity and 67% specificity, and a severity index threshold for oxygen therapy of 0.32 (about 11/36 of the lung score).

It has been reported that the handheld US predicted the composite end point of in-hospital death, mechanical ventilation, shock, and acute decompensated heart failure [68, 90]. Abnormal echocardiogram (defined as left or right ventricular dysfunction or enlargement or moderate/severe valvular regurgitation/stenosis) at the echocardiographic study by HUDs was associated with the need for advanced ventilatory support, acute decompensated heart failure (ADHF), myocardial injury, acute kidney injury (AKI), death, and the composite end point (in-hospital death, mechanical ventilation, shock, and ADHF) with an unadjusted odds ratio (OR) of 7.29 [68]. The lung score (mean 3.7, range 0–20, by the means of a 10-location assessment) was associated with the advanced ventilatory support, anti-COVID-19 medication use, myocardial injury, hospital length of stay, mechanical ventilation, ADHF, in-hospital death, and the composite end point with an unadjusted OR of 1.44 [68].

The survival time of COVID-19 on dry inanimate surfaces is up to 72 h [76, 91]. Therefore, the cleaning of the instruments and the protection of the healthcare workers and patients are key points in the COVID-19 infection management. In patients with suspected/confirmed COVID-19, the US scans are safely conducted with personal protection equipment (clothing, aprons, gowns, shoe covers, double gloving, masks, goggles, face shields) [92]. The ease of HUD decontamination is an unquestioned advantage [93], whereas the high-end US machines need major efforts in terms of time and costs, due to the greater surface area and the additional components (columns, wheels, keyboards, cords, printers, etc.). As matter of fact, the HUDs may be used with the protective covers and the specific cleaning (for the devices and the probes, as well as the

Fig. 5 Bedside abdomen echoscopy report

Surname, name: Weight (kg): Height (cm):
Date:

	Liver segments			
	RHV	MHV	LHV	
PV	7	8	4a	2
	6	5	4b	3
			1	

The portal vein (PV) branches respectively separates superior and inferior liver segments, the right/middle/left hepatic vein (RHV/MHV/LHV) respectively separate the right, middle and left liver segments.

Abdominal aorta (cm)		nv <2.5, 2.5-3 ectasia, >3 aneurysm		
Appendix (cm)		nv MOD <6 mm, WT <2 mm		
Superior Mesenteric A (cm)		nv D <0.5 cm		
Inferior Vena Cava (cm)		nv D <2.1		
Hepatic Veins (cm)		nv D <0.6		
Gallbladder (cm)		nv preprandial WT <0.4, max TDxLD 11x4		
Intrahepatic Duct (cm)		nv <0.4		
Common Hepatic Duct (cm)		nv <0.6		
Common Bile Duct (cm)		nv <0.6, <0.9 in cholecystectomy		
Portal Vein (cm)		nv <1.3, >1.5 in portal hypertension		
Splenic Vein (cm)		nv <1, >1.2 in portal hypertension		
Liver (cm)		nv CCD in MCL <13-15 cm		
Focal Liver Lesion	N:	Dimension:	Site:	GS:
Diffuse Liver Lesion		FLD:	FLD G:	
Pancreas (cm)		nv <0.3 head, <2 body, <2.5 tail		
Pancreatic Duct (cm)		nv <3 mm		
Lymph Nodes (T/L ratio)		nv >2		
Spleen (cm)		nv SL <11 cm, ST <4		
Kidney (cm)		nv TDxLD 4-6x10-12, RCT 1.3-2.5		
Hydronephrosis (cm)		nv APDRP <5	G:	
Adrenal gland		nv < 1		
Bladder (cm)		nv BT <0.8		
Prostate (cm)		nv TD <5, LD<3, APD <4		
Uterus (cm)		nv TD<6, LD<9, APD <3.5; ET <1.5, ETM<0.6		

The sonographer may report the linear abdominal measurements in this template.
Nv=normal value, MOD=maximum outer diameter, WT=wall thickness, A=artery, D=diameter, TD=transverse diameter, LD=longitudinal diameter, max=maximum, CCD=craniocaudal diameter, MCL=midclavicular line, N=numbers, GS=gray scale (hypo/hyper/iso/anechoic lesion), FLD=fatty liver disease, FLD G=fatty liver disease grading (mild, moderate, severe), T/L=transverse/longitudinal diameter, SL=spleen length (distance between the superior and inferior pole), ST=spleen thickness, RCT=renal cortical thickness, APDRP=anterior-posterior diameter of renal pelvis, G=grading, BT=bladder thickness, APD=antero-posterior diameter, ET=endometrial thickness, ETM=endometrial thickness in menopause.

dedicated smartphones) [94–102]. The system and transducers must be cleaned and disinfected after each exam. The COVID-19 units may have dedicated devices (that do not leave the ward), which can be disinfected after each scan (for examples, with disposable wipes) and at the end of each day (with ultraviolet irradiation or plasma circulation air sterilizer) [100, 103, 104]. The reporting room should be periodically cleaned, too.

It is noteworthy that other types of diagnostic radiology exams (CT scans and X-rays) require the transportation of the patient to the radiology department, exactly on the contrary of the POCUS approach, increasing the risk of contamination. Moreover, the HUDs are less expensive than standard POCUS systems, and therefore, a hospital could purchase more HUD units, readily available during times of high patient volume and resource-limited settings.

Conclusion

Even if the CT scan remains the gold standard for the assessment of lung involvement extent in COVID-19 infection [105], the cardio-pulmonary US may be very useful in the viral scenario for additional reasons, such as to avoid irradiation (in pregnancy), to perform serial examinations (limiting X-ray and CT scan use), to predict the need for advanced therapy (mechanical ventilation), to prevent the severe complications, and to ameliorate the multiple end-points.

In conclusion, the routine use of HUDs may ameliorate the management of COVID-19 pandemic, when the specific guidelines for the POCUS approach and the specific procedures for the protection of the patients and professionals from the COVID-19 infection are applied.

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Data Availability Not applicable.

Code Availability Not applicable.

Declarations

Ethics Approval Not applicable.

Consent to Participate Not applicable.

Consent for Publication Not applicable.

Competing Interests The authors declare no competing interests.

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