Bedside Ultrasound in Assessment of 510 Severe and Critical Patients with COVID-19 Pneumonia in Wuhan, China

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Objective: To discuss the value of bedside ultrasound in the diagnosis and treatment of 2019 novel coronavirus diseases (COVID-19).

Methods: Retrospective analysis of the results of bedside ultrasound of 510 patients with COVID-19 in our hospital was done from January 31, 2020 to March 4, 2020.

Results: (1) Among the 510 patients who underwent bedside ultrasound examination, a total of 327 (64.1%) underwent echocardiography, 494 (96.9%) underwent bilateral venous ultrasound examination of lower limbs, 86 (16.9%) underwent bilateral artery ultrasound examination of lower limbs, 48 (9.4%) underwent ultrasound examination of liver, gallbladder, spleen and pancreas, 26 (5.1%) underwent ultrasound examination of kidney, ureter and bladder, and the numbers of patients who underwent ultrasound examination of pericardium, pleural effusion, and peritoneal effusion were 16 (3.1%), 21 (4.1%), and 5 (1%), respectively. (2) Among the 327 patients who underwent bedside ultrasound examination of the heart, 96 (29.4%) showed results of positive for other abnormalities or complications, in which 31 (9.5%) had abnormal left ventricular wall motion, 42 (12.8%) were with valvular heart disease, 3 (0.9%) showed coronary heart disease, 19 (5.8%) showed the enlargement of right heart with pulmonary hypertension (PAH), and 1 (0.3%) had congenital heart disease. In addition, 6 of the 327 echocardiography patients showed negative results (no other abnormalities or complications), accounting for 1.8%. (3) Among the 494 patients who underwent bilateral venous examination of lower limbs, 182 (36.8%) had phlebothrombosis. Eighty-six (86) patients underwent bilateral artery examination of lower limbs, and 63 (73%) of them had positive results, in which 5 patients showed arterial occlusion and the other 57 patients showed atherosclerosis. (4) Thirty-three (33) patients underwent ultrasound examination of liver, gallbladder, spleen, and pancreas, and 23 (70%) of them showed positive results. Among the 26 patients who underwent the urological examination, 7 (26.9%) showed positive results. Additionally, there are 2 positive findings in 21 patients who underwent the examination of pleural effusion (9.5%), and 1 positive case in 5 patients who underwent the examination of abdominal effusion (20%).

Conclusion: Bedside ultrasound is important in the diagnosis and treatment of COVID-19. We hope to make better use of bedside ultrasound to help clinicians get accurate diagnosis and treatment strategies.

Key words: Corona virus disease 2019; Bedside ultrasound; Severe; Critical

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Since the emergence of novel coronavirus pneumonia in Wuhan in December 2019, the development of the epidemic situation has rapidly spread from Wuhan to the other parts of China and other countries. As of March 4, 2020, there were 80,421 confirmed cases nationwide in China (2885 deaths, mortality rate 3.6%), and 95,395 cases were diagnosed globally (3,162 deaths, 3.3% mortality) across 76 countries [1]. Coronavirus disease 2019 (COVID-19) is mainly transmitted through respiratory droplets and close contact, causing varying degrees of consolidation of the lungs, in addition to potentially affecting cardiovascular, hepatobiliary, splenic, and other systemic multiple organ function damage or disease [2-4]. The diagnosis of coronavirus pneumonia mainly relies on viral nucleic acid detection and lung CT, combined with other epidemiological and clinical symptoms [2]. Nucleic acid detection is a blood biochemical indicator. CT is neither real-time nor convenient due to the limitations of the instrument, and it is impossible to comprehensively evaluate the organic lesions of other organs with this imaging modality.

Materials and Methods

Patient Population

The West campus of Union Hospital, Tongji Medical College, Huazhong University of Science and Technology is the admission unit for patients with severe and critical illness (ICU). All patients admitted were diagnosed with both viral pneumonia by pulmonary CT and COVID-19 by a positive COVID-19 nucleic acid test. A retrospective analysis was performed on COVID-19 confirmed patients (n=510) within the West campus from January 31 to March 2, 2020, who underwent bedside ultrasound examinations. According to the "Diagnosis and Treatment Protocol for Novel Coronavirus Pneumonia (Trial Version 7)" which was released by the National Health Commission & State Administration of Traditional Chinese Medicine, the clinical classification criteria for severe and critical cases are as follows: [2]

(1) Severe cases

Adult cases meeting any of the following criteria:

① Respiratory distress (≧ 30 breaths/ min);
② Arterial partial pressure of oxygen (PaO₂)/ fraction of inspired oxygen (FiO₂) ≧ 300 mmHg (1 mmHg=0.133 kPa);
③ Cases with chest imaging that showed obvious lesion progression within 24-48 hours to be > 50% shall be managed as severe cases.

Child cases meeting any of the following criteria:

① Tachypnea (RR ≧ 60 breaths/min (BPM) for infants aged below 2 months; RR ≧ 50 BPM for infants aged 2-12 months; RR ≧ 40 BPM for children aged 1-5 years, and RR ≧ 30 BPM for children above 5 years old) independent of fever and crying;
② Oxygen saturation ≦ 92% on finger pulse oximeter taken at rest;
③ Labored breathing (moaning, nasal fluttering, and infrastrernal, supraclavicular and intercostal retraction), cyanosis, and intermittent apnea;
④ Lethargy and convulsion;
⑤ Difficulty feeding and signs of dehydration.

(2) Critical cases

Cases meeting any of the following criteria:

① Respiratory failure requiring mechanical ventilation;
② Shock;
③ With other organ failure that requires ICU care.

Ultrasound Examination

Depending on the condition, the patient receives bedside ultrasound, including the heart, liver, gallbladder, pancreas, spleen, renal ureter, bladder, and/or arteries and veins of both lower limbs. Bedside ultrasound was performed using a Philips EPIQ 7C ultrasound machine (Philips Medical Systems, Andover, MA) and a Mindray M9 ultrasound machine (Mindray Medical Systems, Shenzhen, China).

Results

Bedside Ultrasound Examinations

There were 510 COVID-19 confirmed patients (219 male and 208 female, aged from 17 to 96 years, with an average age of 62.9 ± 30.2 years) who underwent bedside ultrasound examinations, of which 427 were severe cases (83.7%) and 83 were critical cases (ICU) (16.6%). The critical cases were 47 males and 36 females, aged 27 to 85 years, with an average age of 60.1 ± 25.3 years.

Among these 510 patients, 327 patients (64.1%) had bedside echocardiography (Table 1). Other bedside ultrasound examinations were performed, including bilateral lower limb veins of 494 patients (96.9%), bilateral lower limb arteries of 86 patients (16.9%), hepatobiliary, ancreatic and spleen of 48 patients (9.4%), kidney, ureter and bladder of 26 cases (5.1%), pericardium of 16 cases (3.1%), pleural effusion of 21 cases (4.1%), and peritoneal effusion of 5 cases (1%). The numbers of
ultrasound examinations positive for other abnormalities or complications are shown in Table 2.

**Table 1** Bedside ultrasound examinations of COVID-19 confirmed patients

| Item                                | Severe cases | Critical cases | Total |
|-------------------------------------|--------------|----------------|-------|
| Heart                               | 271          | 56             | 327   |
| Bilateral lower limb veins          | 418          | 76             | 494   |
| Bilateral lower limb arteries       | 76           | 10             | 86    |
| Hepatobiliary, ancreatic and spleen | 21           | 12             | 33    |
| Kidney, ureter and bladder          | 12           | 7              | 19    |
| Pericardium                         | 2            | 0              | 2     |
| Pleural effusion                    | 20           | 1              | 21    |
| Peritoneal effusion                 | 5            | 0              | 5     |

**Table 2** The number positive results for other abnormalities or complications found during ultrasound examinations of COVID-19 confirmed patients

| Item                                | Total | Positive (%) |
|-------------------------------------|-------|--------------|
| Heart                               | 327   | 96 (29.4%)   |
| Bilateral lower limb veins          | 494   | 182 (36.8%)  |
| Bilateral lower limb arteries       | 86    | 63 (73%)     |
| Hepatobiliary, ancreatic and spleen | 33    | 23 (70%)     |
| Kidney, ureter and bladder          | 26    | 7 (26.9%)    |
| Pleural effusion                    | 21    | 2 (9.5%)     |
| Peritoneal effusion                 | 5     | 1 (20%)      |
| Total                               | 992   | 374 (37.7%)  |

**Bedside Echocardiography**

Within the bedside echocardiography of 327 COVID-19 confirmed cases, 96 cases (29.4%) had cardiac structural or functional abnormality, and 6 cases (1.8%) had normal cardiac structure and function. The positive cases were divided into several groups (Table 3), including left ventricular wall motion abnormality (such as reduced left ventricular segmental wall motion and diffuse left ventricular wall motion), valvular disease (i.e., degenerative tricuspid valve stenosis and/or insufficiency, mitral valve prolapse and insufficiency, abnormal tricuspid valve structure and insufficiency) (Fig. 1), coronary heart disease (diagnosed with coronary angiography before admission or after coronary stent implantation), enlarged right heart with pulmonary hypertension (PAH, defined as the right atrium > 4.5 cm, right ventricle >4.0cm [5], tricuspid regurgitation transvalvular pressure + right atrial pressure > 36 mmHg [6,7]), congenital heart disease, and left ventricular diastolic dysfunction (defined as the patients without cardiac structural abnormalities, and is evaluated in accordance with the 2016 ASE/EACVI guidelines for assessing left ventricular diastolic function [8]).

**Bedside Ultrasound Examinations of Bilateral Lower Limb Vessels**

The bedside ultrasound examinations of bilateral lower limb vessels were completed in severe and critical COVID-19 confirmed patients, including scans of veins (494 cases) and arteries (86 cases). Of the 494 vein scans, 182 cases (36.8%) were diagnosed with bilateral lower extremity venous thrombosis (Table 4). Of the 86 patients who underwent bilateral arterial ultrasound examination of lower limb, 63 patients (73%) had arterial abnormalities, of which 6 were arterial occlusion, and the remaining 57 were atherosclerotic plaques (Fig. 2).

**Table 3** Bedside echocardiography findings of COVID-19 confirmed patients

| Item                                | Total (n=327) | Severe cases (n=271) | Critical cases (ICU, n=56) | P value |
|-------------------------------------|--------------|----------------------|--------------------------|---------|
| Left ventricular wall motion abnormality | 31 (9.5%) | 18 (6.6%) | 13 (23.2%) | 0.002 |
| Valvular disease                    | 42 (12.8%)  | 39 (14.4%) | 3 (5.4%)  | 0.150 |
| Coronary heart disease              | 3 (0.9%)    | 3 (1.1%)  | 0 (0%)    | 0.988 |
| Enlarged right heart with pulmonary hypertension | 19 (5.8%) | 14 (5.2%) | 5 (8.9%) | 0.476 |
| Congenital heart disease            | 1 (0.3%)    | 1 (0.4%)  | 0 (0%)    | 0.380 |
| Left ventricular diastolic dysfunction | 225 (68.8%) | 190 (70.1%) | 35 (62.5%) | 0.710 |
| Normal                              | 6 (1.8%)    | 6 (2.2%)  | 0 (0%)    | 0.575 |
Figure 1  Valvular disease. A 73-year-old female patient was admitted to the hospital for 12 days due to fever, with palpitation, chest tightness and shortness of breath. COVID-19 nucleic acid was positive, oxygen saturation was 85%, and emergency bedside ultrasound was performed. (A) X-ray of the lung shows multiple fuzzy patchy shadows in both lungs. (B) CT of the lung shows ground glass changes in both lungs. (C) Bedside ultrasound shows calcification of the aorta (shown by the white arrow), and enlargement of the left heart. (D) Severe insufficiency of closure can be seen in the diastolic period of the aortic valve (shown by the white arrow). (E) Increased muscle trabeculae in the middle and apical segments of the left ventricular sidewall, and abundant muscle sinus spaces (shown by the white arrow). As shown in the head, the dense myocardium is obviously thinner, while the non dense myocardium is 2.3:1. (F) M-mode ultrasound shows the diffuse decrease of left ventricular wall motion, the thickening rate of the left ventricular wall is less than 5mm, and the EF value measured by Simpson is 40%. La, left atrium; LV, left ventricle; AAO, ascending aorta.

Figure 2  Bedside ultrasound showing venous thrombosis of both lower extremities. A 64-year-old female patient was hospitalized with fever and cough aggravation for 7 days. Covid-19 nucleic acid was positive, oxygen saturation was 65%, and ventilator assisted respiration into ICU. (A) X-ray of chest shows patchy shadows of right lung and left middle and lower lung fields, according to the change of viral pneumonia on both sides. (B) CT the lung of shows diffuse distribution of ground glass shadow and grid strip shadow. (C,D) Bedside ultrasound showed thrombosis in popliteal vein (shown by white arrow), CDFI showed no blood flow signal distribution. (E,F) Thrombosis in posterior tibial vein (shown by white arrow), CDFI showed no blood flow signal distribution, posterior tibial artery showed blood flow signal. (G,H) Intramuscular venous thrombosis (shown by the white arrow), CDFI showed no blood flow signal distribution. A, Posterior tibial artery; V, posterior tibial vein.
Table 4  Bedside ultrasound examination positive findings of bilateral lower limb vessels of COVID-19 confirmed patients

| Target vessel                  | Quantity | Number | Percentage |
|-------------------------------|----------|--------|------------|
| Intermuscular vein            |          | 68     | 37.40%     |
| Posterior tibial vein         |          | 45     | 24.70%     |
| Peroneal vein                 |          | 41     | 22.50%     |
| Iliac vein                    |          | 18     | 9.90%      |
| Superficial femoral vein      |          | 4      | 2.20%      |
| Great saphenous vein          |          | 4      | 2.20%      |
| Small saphenous vein          |          | 2      | 1.10%      |
| Total                         |          | 182    | 100%       |

Other Bedside Ultrasound Examinations

Of the 33 patients with hepatobiliary, pancreatic, and spleen bedside ultrasound examinations, 23 cases (70%) were abnormal, including fatty liver, liver occupying, cholecystitis, gallbladder stones, and splenomegaly. Among the 26 patients who underwent urinary system bedside ultrasound examinations, 7 cases (26.9%) were abnormal, including renal cysts, renal parenchymal occupying, renal stones, and ureteral stones. Of the 21 patients with pleural effusion bedside ultrasound examinations and 5 patients with peritoneal effusion bedside ultrasound examinations, 2 cases had pleural effusion and 1 had ascites, respectively (Fig. 3-4).

Discussion

The lung is the main target organ of COVID-19, which causes pulmonary solid changes of varying degrees. The principal clinical manifestations are fever, dry cough, fatigue, and wheezing. In severe cases, it can develop into severe pneumonia, acute respiratory distress syndrome, and systemic multiple organ dysfunction [9]. With the development of ultrasound technology, it has been widely used to detect lung lesions, which can help assess the status of lung lesions [4]. The severe and critical cases of COVID-19 have obvious lung consolidation and affect the patient's breathing significantly. In addition, cardiovascular and other system dysfunction can be involved at the same time. Patients with multiple organ abnormalities have significantly higher critical illness rates and mortality [10,11].

Additional case research showed that COVID-19 can also involve the cardiovascular system and cause severe myocardial damage, which will aggravate the disease and affect the prognosis [4,10,11]. Of the 327 COVID-19 patients who underwent bedside echocardiography in this study, 96 cases had ultrasound results positive for
other abnormalities or complications, accounting for 29.4%. Depending on the type of heart disease, these positive findings were divided into 13 cases (9.5%) of left ventricular wall motion abnormalities, 42 cases of valvular disease (12.8%), 3 cases of coronary heart disease (0.9%), 19 cases of enlarged right heart with pulmonary hypertension (PAH) (5.8%), and 1 case (0.3%) of congenital heart disease. Left ventricular wall motion abnormalities included segmental and diffuse left ventricular wall motion. Due to the fact that these patients were unable to have coronary angiography or coronary CT performed to confirm these findings, etiology was not clear. Therefore, we can only classify them generally as abnormal left ventricular wall movement. In addition, according to bedside ultrasound combined with myocardial enzymes and electrocardiograms, it is helpful to provide additional information for clinical diagnosis and treatment strategy. The 24 cases that were positive for valvular disease included degenerative aortic valve stenosis and/or insufficiency, mitral valve prolapse and insufficiency, and abnormal tricuspid valve structure and insufficiency. Valve dysfunction can also give rise to respiratory symptoms such as panic and shortness of breath. It is easy to ignore cardiac abnormalities because of the similar symptoms of COVID-19. In 23 cases of coronary heart disease, patients had been diagnosed with coronary angiography before admission or after coronary stent implantation. Most patients with coronary heart disease can only wait for further diagnosis. At this time, bedside ultrasound can show the presence of segmental wall motion abnormalities and reduced cardiac function, which is beneficial for clinical treatment.

Pulmonary heart disease can occur in patients with COVID-19, with enlarged right heart and/or pulmonary hypertension (PAH). In this study, 2 of 19 patients with enlarged right heart had moderate pulmonary hypertension, and the rest were mild pulmonary hypertension. No cases of right ventricular systolic dysfunction were observed.

From the perspective of the age structure of COVID-19 cases, it is mainly concentrated in patients with low immunity and middle-aged and elderly patients. The average age of patients in this study was 62 years. Degeneration in the elderly, such as reduced left ventricular diastolic function, is a normal physiological change. In this study, there were 225 cases of cardiac degeneration, accounting for 68.8%. Only 6 cases had normal heart classification, accounting for 1.8%.

Among 494 patients with venous lower limb ultrasound examination and 86 patients with arterial lower limb ultrasound examination, 182 cases of bilateral lower extremity venous thrombosis were found, with an incidence of 36.8%. Thrombosis is most common in the intramuscular, posterior tibial, and peroneal veins. Of the 83 patients with bed immobilization in the ICU, 43 had venous thrombosis in the lower extremities, and the incidence was 52%. For the 86 patients undergoing arterial ultrasound examination of bilateral lower extremities, arterial occlusion was found in 6 cases, and atherosclerotic plaque was found in the remaining 57 cases.

According to the "Diagnosis and Treatment Protocol for Novel Coronavirus Pneumonia (Trial Version 7)" which was released by National Health Commission & State Administration of Traditional Chinese Medicine, COVID-19 also affects the spleen, hilar lymph nodes, bone marrow, liver, gallbladder, kidneys and other organs. Of the 33 patients with hepatobiliary, pancreatic, and spleen bedside ultrasound examinations, 23 cases (70%) were abnormal, including fatty liver, liver occupying, cholecystitis, gallbladder stones, and splenomegaly. Among the 26 cases who underwent urinary system ultrasound examinations, 7 patients (26.9%) were abnormal, including renal cysts, renal parenchymal occupying, renal stones, and ureteral stones. Whether these positive characteristics are due to COVID-19 or previous medical history requires further follow-up.

In our study, the positive results for other abnormalities or complications found during bedside ultrasound examination of severe and critical COVID-19 patients was 37.7%. Bedside echocardiography is a convenient, accurate, rapid assessment method that can be used in isolated wards for detecting lesions in the lungs and other organs. Based on "Diagnosis and Treatment Protocol for Novel Coronavirus Pneumonia (Trial Version 7)", diagnosis mainly relies on pulmonary CT. Ultrasound is only used for non-invasive monitoring of hemodynamics in severe and critical patients. As such, the clinical value of bedside ultrasound in the diagnosis and treatment of COVID-19 is greatly underestimated.

In conclusion, this study highlights the importance of bedside ultrasound in the diagnosis and treatment of COVID-19. We hope to make better use of bedside ultrasound to help clinicians get accurate diagnosis and treatment strategies.

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Conflict of Interest
The authors have no conflict of interest to declare.

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