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Using remote consultation to enhance diagnostic accuracy of bedside transthoracic echocardiography during COVID-19 pandemic

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Abstract

Objective: The aim of this study was to evaluate the clinical significance of remote consultation over bedside transthoracic echocardiography (RC-B-TTE) for patients with coronavirus disease 2019 (COVID-19).

Methods: Five frontline echocardiographers performed and interpreted B-TTE for 30 patients with COVID-19 in the isolation wards, and the on-site B-TTE reports (OSR) were generated. Then remote consultation over the 30 B-TTE studies was conducted by two experienced echocardiographic consultants while blinded to the OSR, and the corresponding remote consultation reports (RCR) were generated. Subsequently, the five frontline echocardiographers were convened together to discuss the difference between the OSR and RCR, and to confirm the correct interpretation and the misdiagnosis using a "majority-vote" consensus as the diagnostic "gold standard". Afterwards the reasons for the misdiagnosis were given by the frontline echocardiographers themselves. The inter-rater agreement between the OSR and the "gold standard" was assessed using *Kappa* coefficient and percent agreement.

Results: Complete correctness of the 30 copies of the RCR were determined by the 5 frontline echocardiographers. The reliability of the OSR in the findings of cardiac chamber dilation, left ventricular hypertrophy and pulmonary hypertension were weak (*Kappa* <0.6). The reliability of the OSR in the recognition of major cardiac abnormalities was very weak (*Kappa* =0.304, percent agreement =63.3%). Misdiagnosis of major abnormalities was found in 11 copies of OSR (11/30, 36.7%).

Conclusions: The protocol of RC-B-TTE has shown noticeable superiority in ameliorating diagnostic accuracy of echocardiography, which should be generalized to clinical practice during the COVID-19 or similar pandemic.

KEYWORDS

heart, pandemic, tele-echocardiography, telehealth, telemedicine, tele-ultrasonography

1 | INTRODUCTION

Coronavirus disease 2019 (COVID-19) is a highly infectious, lethal and serious threat to human health. The cardiac injury occurred in many patients with COVID-19,[1-4] and the incidence was recorded as high as 27.8%.[5] Studies showed that most critical COVID-19 patients with underlying cardiovascular diseases exhibited a higher morbidity and mortality.[4,6,7] Therefore, it is crucial to discover the possible cardiac abnormalities promptly and effectively to facilitate treatment decision for the patients with COVID-19.

Using remote consultation or telemedicine in disasters and public health emergencies has been confirmed to be very useful by previous studies.[8-11] At the early phase of the COVID-19 outbreak, the medical members of Ultrasound Medicine of Chinese Medical Association proposed implementing the protocol of remote consultation over bedside transthoracic echocardiography (RC-B-TTE) into daily clinical practice to optimize the application during the pandemic.[12,13] Theoretically, echocardiographic diagnostic accuracy and quality control can be ensured with a collective wisdom of experienced echocardiographic experts via remote consultation. However, this theoretical advantage of the RC-B-TTE during the pandemic is still to be confirmed. Thus, the aim of this study was to evaluate the clinical significance of RC-B-TTE for patients with COVID-19.

2 | METHODS

2.1 | Patients

This study was conducted according to the World Medical Association Declaration of Helsinki, and was approved by the Institutional Research Committee of both the Sichuan Academy of Medical Sciences & Sichuan Provincial People's Hospital and the Public Health Clinical Center of Chengdu. A group of 30 adult patients with COVID-19 who had been treated at the Public Health Clinical Center of Chengdu from 20/01/2020 to 25/03/2020 were enrolled in this study. All of the patients with COVID-19 were confirmed with the Viral Nucleic Acid Kit (Health, Ningbo, China).

2.2 | B-TTE performance and on-site interpretation

The B-TTE were performed in the isolation wards at the Public Health Clinical Center of Chengdu using the Philips Spark (Philips Medical Systems) or Mindray M8 Super (Mindray Corp, Shenzhen, China) color Doppler ultrasound system. Five frontline echocardiographers were dispatched to perform the B-TTE for the 30 inpatients with COVID-19. Each echocardiographer completed B-TTE image acquirement and generated the on-site reports (OSR) for six patients. The procedure of the B-TTE performance and the personal protection of frontline echocardiographers were conducted strictly according to the detailed recommendation.[12,13] Echocardiographic image were acquired through the left parasternal long-axis view, parasternal short-axis views (including aortic root, pulmonary artery, mitral orifice, left ventricular papillary muscle, and apical short-axis views), apical views (including apical two-, three-, four-, and five-chamber views), subcostal views (including four-chamber view, long-axis view of inferior vena cava). The measurement of dimensions and velocities, and the cardiac chamber quantification and ventricular systolic and diastolic function assessment were completed on the echocardiographic machine according to the recommendations.[12,13] Then the OSR was produced by the frontline echocardiographers based on their personal experience and echocardiographic expertise.

2.3 | Protocol of RC-B-TTE

All stored B-TTE DICOM images were transferred to the remote echocardiography consultation center at Sichuan Academy of Medical Sciences & Sichuan Provincial People's Hospital. Then two experienced echocardiographic consultants there reevaluated the B-TTE images case by case according to the recommendations and guidelines.[12-16] The images were replayed using a medical DICOM viewer, and the dimensions and velocities were remeasured. The remote consultation reports (RCR) for each B-TTE were jointly generated by the two echocardiographic consultants based on both their visual assessment and the measurements.

2.4 | Qualifications and expertise in echocardiography

All of the 5 frontline echocardiographers and the two echocardiographic consultants were qualified Chinese Medical Practitioner of Ultrasonography. Among the five frontline echocardiographers, three doctors were attending physicians and two doctors were associate chief physicians. The two echocardiographic consultants were associate chief physician and chief physician respectively. All the seven doctors had more than 5 years of experience in performing and interpreting echocardiography. The main difference was that the two echocardiographic consultants could perform various special echocardiography procedures (ie, transesophageal, stress, and intraoperative echocardiography), while the five frontline echocardiographers could not. Moreover, the two echocardiographic consultants were more familiar with the relevant international echocardiographic recommendations and guidelines [14-16] than the five frontline echocardiographers.

2.5 | Summary of the B-TTE reports

According to the recommendations for quality echocardiography laboratory operations,[17] 13 basic fields describing cardiac anatomy and function were rated as either “NORMAL” or “ABNORMAL” for every OSR and RCR. Then, 11 types of specific cardiac abnormalities were summarized for every OSR and RCR. Subsequently, the five frontline

echocardiographers were convened together to discuss and confirm the difference in the 13 basic fields and the 11 types of specific cardiac abnormalities between the OSR and RCR. A "majority-vote" consensus was used as the diagnostic "gold standard", against which the correct interpretation and the misdiagnosis of the B-TTE were determined. The "majority-vote" consensus defined as no less than 3 out of the 5 frontline echocardiographers had consistent votes on the B-TTE diagnosis. Afterward the reasons for the misdiagnosis were given by the frontline echocardiographers themselves.

2.6 | Statistical analyses

Statistical analyses were performed using SPSS 16.0 (SPSS). Categorical variables were expressed as a case (percentage). Continuous variables with normal distribution were summarized as mean ± standard deviation, and those without normal distribution were summarized as median (interquartile range). The inter-rater agreement between the OS-R and "gold standard" was analyzed using *Kappa* tests and percent agreement analyses. The difference was considered as statistical significance when *P* is less than .05.

3 | RESULTS

3.1 | General clinical information

The 30 patients with COVID-19 included 16 males and 14 females, aged from 25 to 87 (52 ± 15) years old. The moderate, severe, and critical COVID-19 were 15, 9, and 6 cases respectively. The clinical characteristics, lung CT, laboratory findings, and oxygen treatment of the 30 patients with COVID-19 on the day of admission were summarized in Table 1. The oxygen treatments were applied to 21 patients, and four of them underwent mechanical ventilation.

3.2 | Inter-rater agreement

Complete correctness of the 30 copies of the RCR was determined by the five frontline echocardiographers themselves using "majority-vote" consensus. Thus, the diagnosis recorded in the RCR was confirmed as the "gold standard", against which the diagnostic reliability of the OSR was assessed.

The diagnostic agreement on the 13 basic fields of cardiac anatomy and function between the OSR and RCR in 30 patients with COVID-19 were shown in Table 2. The reliability of the OSR was weak in the diagnosis of abnormalities in right ventricle, right atrium, aorta, pulmonary artery, and interventricular septum (*Kappa* <0.6).

The diagnostic agreement on the findings of specific echocardiographic abnormalities between the OSR and RCR of B-TTE of the 30 patients with COVID-19 were shown in Table 3. The reliability of the OSR in findings of cardiac chamber dilation, left ventricular hypertrophy and pulmonary hypertension were weak (*Kappa* <0.6).

TABLE 1 The clinical characteristics, lung CT, laboratory findings, and oxygen treatment of the 30 patients with COVID-19 on the day of admission

Signs and symptoms	
Temperature, °C	37.15 ± 0.81
Respiratory rate, bpm	21 (19.5-22.5)
Pulse rate, bpm	85.20 ± 12.83
Brachial artery systolic pressure, mmHg	131.25 ± 16.28
Brachial artery diastolic pressure, mmHg	86.28 ± 16.08
Fever, n (%)	28 (93.33)
Cough, n (%)	25 (83.33)
Sputum, n (%)	15 (50.00)
Short of breath, n (%)	18 (60.00)
Peripheral oxygen saturation <0.95, n (%)	7 (23.33)
PaO_2 < 60 mm Hg, n (%)	7 (23.33)
PaO_2/FiO_2 < 200 mm Hg, n (%)	12 (40.00)
Comorbidity	
Hypertension, n (%)	5 (16.67)
Type II diabetes mellitus, n (%)	5 (16.67)
Hyperlipidemia, n (%)	5 (16.67)
Chronic renal failure, n (%)	2 (6.67)
Lung computer tomography	
Bilateral patchy ground-glass opacities, n (%)	29 (96.67)
Lung consolidation, n (%)	9 (30.00)
Hydrothorax, n (%)	7 (23.33)
Laboratory findings	
White blood cell, 10^9/L	4.89 ± 1.07
Lymphocyte rate <20%, n (%)	16 (53.33)
Hemoglobin, g/L	131.50 ± 18.89
C-reactive protein >5 mg/L, n (%)	21 (70.00)
NT-proBNP >121 pg/mL, n (%)	11 (36.67)
CK-MB >4.94 ng/mL, n (%)	2 (6.67)
Myoglobin >72 ng/mL, n (%)	5 (16.67)
hs-cTnT >14 pg/mL, n (%)	5 (16.67)
Oxygen Treatment	
Oxygen inhalation, n (%)	17 (56.57)
Noninvasive mechanical ventilation, n (%)	2 (6.67)
Invasive mechanical ventilation, n (%)	2 (6.67)

Note: Fever was defined as temperature ≥37.3 ℃. PaO2/FiO2, the ratio of arterial oxygen partial pressure to fractional inspired oxygen; CK-MB, isoenzyme MB of creatine kinase; NT-proBNP, amino-terminal pro-brain natriuretic peptide; hs-cTnT, high-sensitivity troponin T.

The reliability of the OSR in the recognition of major cardiac abnormalities was very weak (*Kappa* =0.304, percent agreement =63.3%).

3.3 | Misdiagnosis

According to the results of the "majority-vote" consensus, misdiagnosis of major abnormalities was found in 11 copies of OSR (11/30,

TABLE 2 The diagnostic agreement on the 13 basic fields describing cardiac anatomy and function as "Normal" or "Abnormal" between the on-site reports (OSR) and remote consultation reports (RCR) of bedside transthoracic echocardiography (B-TTE) of the 30 patients with COVID-19

	OSR, n (%)	RCR, n (%)	*P* value of McNemar test	*Kappa* value (SE)	Approx *P* value	Percent agreement (%)
Global positive	19 (63.3)	19 (63.3)	1.000	0.569 (0.156)	.002	80.0
Left ventricle	12 (40.0)	15 (50.0)	.250	0.800 (0.107)	<.001	90.0
Left atrium	3 (10.0)	5 (16.7)	.500	0.714 (0.187)	<.001	93.3
Right ventricle	2 (6.7)	5 (16.7)	.250	0.526 (0.228)	.001	90.0
Right atrium	2 (6.7)	5 (16.7)	.250	0.526 (0.228)	.001	90.0
Aortic valve	4 (13.3)	4 (13.3)	1.000	1.000 (0.000)	<.001	100.0
Mitral valve	7 (23.3)	6 (20.0)	1.000	0.902 (0.096)	<.001	96.7
Tricuspid valve	4 (13.3)	4 (13.3)	1.000	1.000 (0.000)	<.001	100.0
Pulmonic valve	5 (16.7)	6 (20.0)	1.000	0.889 (0.109)	<.001	96.7
Pericardium	2 (6.7)	3 (10.0)	1.000	0.783 (0.209)	<.001	96.7
Aorta	1 (3.3)	3 (10.0)	.500	0.474 (0.306)	.002	93.3
Pulmonary artery	1 (3.3)	4 (13.3)	.250	0.366 (0.269)	.010	90.0
Inferior vena cava	3 (10.0)	3 (10.0)	1.000	1.000 (0.000)	<.001	100.0
Interventricular septum	6 (20.0)	8 (26.7)	.687	0.444 (0.189)	.029	80.0

Note: The n (%) represent the case (percentage) of abnormality.

TABLE 3 Diagnostic agreement on the findings of specific echocardiographic abnormalities between the OSR and RCR of B-TTE of the 30 patients with COVID-19

	OSR, n (%)	RCR, n (%)	*P* value of McNemar test	*Kappa* value (SE)	Approx *P* value	Percent agreement (%)
Cardiac chamber dilation	3 (10.0)	7 (23.3)	.125	0.535 (0.192)	.001	86.7
LV hypertrophy	6 (20.0)	8 (26.7)	.687	0.444 (0.189)	.013	80.0
LV SWMA	1 (3.3)	2 (6.7)	1.000	0.651 (0.321)	<.001	96.7
Valvular structure and function	11 (36.7)	10 (33.3)	1.000	0.927 (0.072)	<.001	96.7
PH	2 (6.7)	6 (20.0)	.125	0.444 (0.215)	.003	86.7
RAP elevation	3 (10.0)	3 (10.0)	1.000	1.000 (0.000)	<.001	100.0
PE	2 (6.7)	3 (10.0)	1.000	0.783 (0.209)	<.001	96.7
LVSD	2 (6.7)	2 (6.7)	1.000	1.000 (0.000)	<.001	100.0
LVDD	10 (33.3)	12 (40.0)	.500	0.857 (0.097)	<.001	93.3
RVSD	2 (6.7)	2 (6.7)	1.000	1.000 (0.000)	<.001	100.0
RMA	12 (40.0)	19 (63.3)	.065	0.304 (0.152)	.063	63.3

Note: The *P* values were calculated with the McNemar test, and the Approx *P* values were calculated with the *Kappa* test.

Abbreviations: LV, left ventricular; LVDD, left ventricle diastolic dysfunction; LVSD, left ventricle systolic dysfunction; PE, pericardial effusion; PH, pulmonary hypertension; RAP, right atrial pressure; RMA, recognition of major abnormalities; RVSD, right ventricle diastolic dysfunction; SWMA, segmental ventricular wall motion abnormality. Other abbreviations as in Table 2 and 3.

36.7%). The critical misdiagnosis included pulmonary artery thromboembolism (Figure 1) one case, right heart enlargement (Figure 2) three cases, pulmonary hypertension four cases, thickened left ventricular wall (Figure 3) four cases, and small pericardial effusion (Figure 3) two cases.

The misdiagnosis of the on-site B-TTE reports and the possible reasons from the five frontline echocardiographers themselves were summarized in Table 4. The reasons mainly included: (a) Personal protective equipment might have negative influences on the performance and interpretation of the B-TTE. For example, three frontline echocardiographers mentioned that fog developed on the Goggles might have blurred their vision and affect the accuracy of OSR. (b) The performance and interpretation of the B-TTE might be affected by the equipment in the isolation wards. In this study, oxygen treatment were applied to assist breathing in 21 (70.0%) patients, and four of them underwent mechanical ventilation. Those

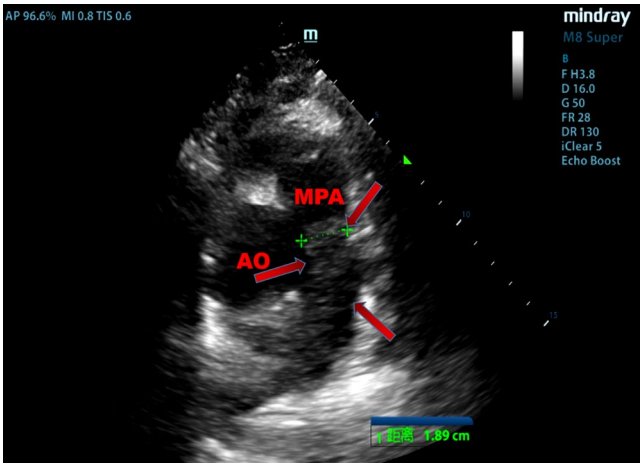

FIGURE 1 Pulmonary artery thromboembolism in a patient with COVID-19. Legend: Using remote consultation over bedside transthoracic echocardiography (RC-B-TTE), a mass with moderate intensity echo located in the main pulmonary artery of a critical COVID-19 patient (arrow) was discovered. The diagnosis of "pulmonary artery thromboembolism" had been missed by the frontline echocardiographer. AO, aorta; MPA, main pulmonary artery

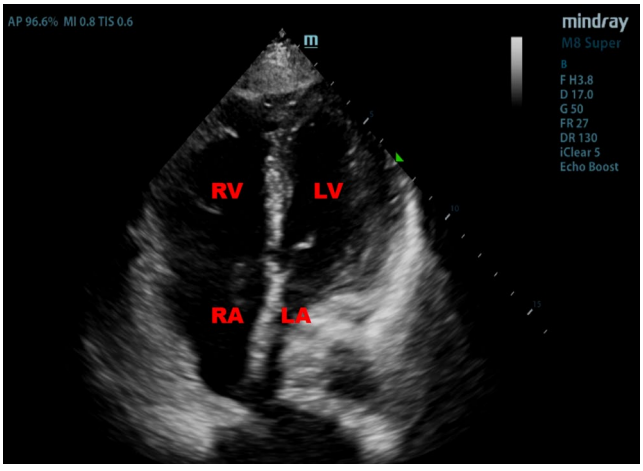

FIGURE 2 Right heart enlargement in a patient with COVID-19. Legend: Using RC-B-TTE, the enlarged right heart in a critical patient with COVID-19 was confirmed visually by the experienced remote consultants, which was missed by the frontline echocardiographer. This static image was obtained from the echocardiographic video using "Print Screen". RV, right ventricle; RA, right atrium; LV, left ventricle; LA, left atrium. Other abbreviations as in Figure 1

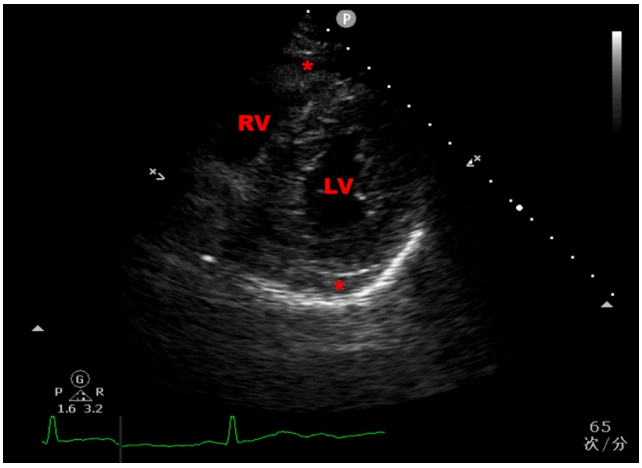

FIGURE 3 Thickened left ventricular wall and small pericardial effusion in a patient with COVID-19. Legend: Using RC-B-TTE, thickened intraventricular septum and left ventricular wall and small pericardial effusion* were found in a critical COVID-19 patient, which had been missed by the frontline echocardiographer. Abbreviations as in Figures 1 and 2

treatment-related medical equipment and/or the vital sign monitors in the isolation wards actually narrowed the operable space, and the echocardiographic performance might have been affected by the special working conditions (Figure 4). (c) The experience and expertise of the frontline echocardiographers might be inadequate to interpret every echocardiographic image correctly. (d) The special training in echocardiography might be inadequate. Three out of the five frontline echocardiographers had not been trained in echocardiographic examination and interpretation at an authoritative echocardiography laboratory. (e) The accuracy of OSR might have been affected by the hasty performance of the B-TTE. Some frontline echocardiographers mentioned that psychological pressure from the fear of being infected by the COVID-19 virus in the isolation wards might have expedited the process. They also pointed out that sometimes they were compelled to finish the performance of echocardiography because of the relatively limited working hours allocated to each patient.

4 | DISCUSSION

The B-TTE plays an important role in providing clinicians with essential information about the cardiac structure, hemodynamics, and function. However, the on-site B-TTE interpretation might be distorted to some extent due to the personal experience and level of expertise in echocardiography, the harsh working condition of COVID-19 isolation wards, and the cumbersome personal protective equipment.

4.1 | Inaccuracy of the on-site B-TTE interpretation

The most notable result of this study was that the on-site interpretation had missed some crucial cardiac abnormalities in the B-TTE images. The misdiagnosis included pulmonary embolism, right heart enlargement, pulmonary hypertension, thickened LV wall, and small pericardial effusion. These cardiac abnormalities have been proved very important for treatment decision-making. For instance: pulmonary embolism is closely associated with hemodynamic instability and mortality of the patients with COVID-19,[18] right heart has been supposed to be in the eye of the COVID-19 storm,[19] and

TABLE 4 The misdiagnosis of the on-site B-TTE reports and the possible reasons from the 5 frontline echocardiographers themselves

Misdiagnosis	Number (false negative)	Reasons from the frontline echocardiographers
Cardiac chamber dilation	4 (4)	
Left atrium	2 (2)	1
Right atrium and ventricle	3 (3)	1-6
Left ventricular hypertrophy	6 (4)	1, 2, and 4
Pulmonary hypertension	4 (4)	1-7
Left ventricular SWMA	1 (1)	1, 2, and 4
Small pericardial effusion	1 (1)	1
Pulmonary embolism	1 (1)	4, 7
LVDD	1 (1)	3
RMA	11 (9)	1-7

Note: Reasons given by the specific frontline echocardiographer themselves are represented by # 1, 2, 3, 4, 5, 6, and 7. # 1: Might be affected by the personal protective equipment. # 2: Experience and echocardiographic expertise were inadequate. # 3: Had not received adequate training in echocardiography. # 4: Might be affected by hasty performance and interpretation of the B-TTE images. Either because of the psychological pressure from fear of being infected by the COVID-19 virus, or due to the relatively limited working hours allocated to each patient. # 5: Might be affected by the equipment in the wards. # 6: Might be affected by the posture of the patient. # 7: Uncertainty, might be affected by some above-mentioned factors. Abbreviations as in Table 2 and 3.

FIGURE 4 Narrowed operable space of the COVID-19 isolation wards. Legend: This photograph shows that a front-line echocardiographer was performing bed-sideechocardiography for a COVID-19 patient in an isolation ward. The images acquisition and interpretation might had been affected by several factors, such as the heavy personal protective equipment and the narrowed operable space

myocardial edema is a manifestation of the acute COVID-19-related myocarditis.[20]

The on-site interpretation of B-TTE by the frontline echocardiographers has been widely acknowledged as a clinical routine in China. Although B-TTE is highly regarded as a powerful cardiac imaging technique, the results of this pilot study proved that the diagnostic accuracy of the on-site interpretation was very poor or even fairly disappointing. The potential causes of the misdiagnosis given by the frontline echocardiographers themselves included: (a) the inadequate personal experience and expertise in interpreting echocardiography; (b) the ill effects of personal protective equipment; (c) the austere working conditions of the isolation wards; and (d) the personal psychological pressure.

The quality of B-TTE reports can be significantly degraded by both the operator dependence of the frontline echocardiographers and the special conditions of the isolation wards for COVID-19 patients. Inadequate experience and insufficient expertise in the interpretation of the B-TTE images might have heavily hindered the frontline echocardiographers from judging B-TTE images accurately. The fact that a huge intrapulmonary thrombus was overlooked might partly demonstrate that the frontline echocardiographer was inexperienced in echocardiographic interpretation. Moreover, a significant discrepancy in the diagnosis of pulmonary hypertension was found. Pulmonary hypertension can be easily diagnosed using echocardiography by experienced echocardiographers in relaxed condition. However, the frontline echocardiographers in this study acknowledged that they were not familiar with the relevant international guidelines for the echocardiographic assessment of the right heart,[16] and had not received adequate echocardiographic training. Therefore, we deduced that the discrepancy in the diagnosis of the right heart enlargement and pulmonary hypertension was most possible due to inexperience. Furthermore, the negative influence of the special working conditions of the COVID-19 isolation wards on the diagnostic accuracy could not be disregarded. Firstly, the operable space for the B-TTE performance is often cramped in the isolation wards for COVID-19 patients. Secondly, because the virus of COVID-19 is extremely contagious, frontline doctors must wear special personal protective equipment, such as: protective clothing, N95 masks or above, disposable medical work caps, Goggles, latex gloves, comprehensive protection face mask, or respiratory protective devices. Our

frontline echocardiographers expressed that the personal protective equipment might have affected the B-TTE image acquisition, the echocardiographic measurement, and interpretation. Thirdly, severe and critical patients with COVID-19 are usually unable to coordinate into a special position, which might prevent echocardiographers from obtaining the standard cardiac views. Fourthly, the equipment and other facilities in the isolation wards could also interference with the B-TTE image acquisition and interpretation. Lastly, in China, an echocardiographer often needs to serve a large number of patients, so the time allocated to each patient is limited. In this study, some frontline echocardiographers implied that due to limited working hours, it was difficult for them to carefully analyze and interpret all the echocardiographic views described in the recommendation.[12,13] Therefore, it is necessary and imperative for echocardiography-related staff to seek a better B-TTE workflow to obtain reliable B-TTE diagnostic information during the pandemic.

4.2 | Advantages of remote consultation

Evolving telemedicine technology has created many possibilities for clinical practice.[10,11] Some of these telemedical services have already had a significant impact on medical practice in developed countries, notably tele-echocardiography.[21] The remote diagnosis of echocardiography or tele-echocardiography can be realized via two kinds of transmission architectures, namely store and forward, or real-time transmission. Previous studies indicate that tele-echocardiography is a reliable and cost-effective diagnostic method; which can improve patient care, ameliorate echocardiography quality, enhance sonographer proficiency, and promote the expansion of medical practice.[22,23]

Although the protocol of tele-echocardiography has so many merits, almost all echocardiographic examinations and interpretations are still performed face-to-face by a single echocardiographer in Chinese everyday clinical practice at present. In this study, we conducted an offline remote consultation on B-TTE and found it had a significant advantage in improving diagnostic accuracy over the traditional on-site interpretation. It is a generally accepted fact that the diagnostic accuracy of echocardiography is not only a function of quantitative parameters but also of the subjective decision of the operators, which depend heavily on their personal echocardiographic experience and expertise. As a consultation team usually consists of a team of experienced experts in the fields of echocardiography and cardiology, the remote consultation would help reduce the operator dependence to the lowest level by using the collective wisdom of the experts. Moreover, we considered that remote consultation might have some other potential advantages which could help ameliorate the echocardiographic diagnostic accuracy for patients with COVID-19. These additional advantages are as follows: (a) The relatively comfortable and relaxed working environment of the remote echocardiographic consultation center is conducive for medical consultants to make more accurate interpretation on the B-TTE images. The remote consultants obviously do not have to bear the psychological pressure from the fear of viral infection, which the frontline echocardiographers might usually have. (b) High-end medical image analysis software equipped in the remote consultation centers could facilitate the analysis and interpretation by replaying and reassessing the stored echocardiographic images. (c) Remote consultation could spare a lot of time for the on-site echocardiographers to acquire higher-quality B-TTE images by handing over the task of echocardiographic interpretation to remote consultants. (d) It is possible for one experienced echocardiographer in a remote consultation center to guide more frontline echocardiographers in different isolation wards through the echocardiographic examination processes. Thus, the problem of scarce experienced echocardiographic experts can be partly solved by the protocol of tele-echocardiography. (e) Assisting frontline echocardiographers in improving the quality of the bedside echocardiographic images must be one of the potential advantages of the real-time remote echocardiographic consultation. An important significance of a real-time remote consultation is to advise examiners whether there is a shortage of acquired images and whether reacquiring images is necessary. Moreover, using real-time tele-echocardiography, experienced remote consultants might also be able to improve the image quality by advising the on-site examiners whether the echocardiographic machine should be adjusted, and how to acquire a better cardiac view. Therefore, RC-B-TTE could optimize the procedure of B-TTE performance for COVID-19 patients, achieve reliable B-TTE interpretation, and facilitate better health care during the COVID-19 or similar pandemic.

4.3 | Limitations and perspectives

As a useful protocol for investigating cardiac pathophysiology on remotely-located patients, tele-echocardiography has been widely used in developed countries.[24-28] In China, tele-echocardiography has not been implemented into the daily clinical practice yet. The off-line RC-B-TTE used in this study had a time delay and did not benefit the COVID-19 patients involved. In this study, the remote diagnosis was performed on the uploaded images after the examinations, and the experienced remote consultants had not been able to advise the frontline examiners on the B-TTE performance. We acknowledge that if we had used real-time remote consultation as the study protocol, the results would be even better to elucidate the practical benefits of real-time remote diagnosis. Although we found that the working conditions of COVID-19 wards could be one of the potential reasons for the echocardiographic misdiagnosis, the accurate negative influence of COVID-19 wards on B-TTE is still to be determined. To investigate the accurate negative influence of the working conditions of COVID-19 wards on the diagnostic accuracy of B-TTE, it is reasonable to enroll some patients without COVID-19 as another contrast group in the further study.

Pilot studies showed that 5G-based robot-assisted tele-ultrasonography is a new feasible strategy for real-time cardiopulmonary assessment during COVID-19 pandemic.[29,30] In these studies, robots replaced the frontline ultrasonographers to obtain the parasternal long-axis view and cardiac apical four-chamber view, and brief echocardiographic assessments were realized. These strategies can help both frontline doctors and remote consultants avoid exposure to the deadly infectious virus. But at present, the robot has not been able to perform a comprehensive echocardiographic examination.

5 | CONCLUSIONS

This study found that some very simple but crucial important cardiac abnormalities were missed by the on-site echocardiographic interpretation in the COVID-19 isolation wards; although the frontline echocardiographers were not novices, and also not poorly trained or completely inexperienced staff. On the contrary, RC-B-TTE has shown noticeable superiority in ameliorating diagnostic accuracy over the on-site interpretation from the frontline echocardiographers. As an important field of telemedicine, the protocol of RC-B-TTE or tele-echocardiography has obviously technical superiority and should be generalized to clinical practice during the COVID-19 or similar pandemic without delay.

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CONFLICT OF INTERESTS

No competing financial interests exist.

AUTHOR CONTRIBUTIONS

Lixue Yin and Jun Lin made equally essential contribution to this work, thus we list both of them as co-corresponding author. All authors have significant contribution to this work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

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