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Characteristics of Pulmonary Auscultation in Patients with 2019 Novel Coronavirus in China

Bo Wang[a] Yanbin Liu[b] Ye Wang[a] Wanhong Yin[c] Tao Liu[d] Dan Liu[a] Diandian Li[a] Mei Feng[a] Yanlin Zhang[a] Zong'an Liang[a] Ziqiao Fu[e] Siyun Fu[f] Weimin Li[a] Nian Xiong[g] Gang Wang[a] Fengming Luo[a]

[a]Department of Respiratory and Critical Care Medicine, West China Hospital of Sichuan University, Chengdu, China; [b]Department of Infectious Diseases, West China Hospital of Sichuan University, Chengdu, China; [c]Department of Critical Care Medicine, West China Hospital of Sichuan University, Chengdu, China; [d]Department of Cardiology, Wuhan Red-Cross Hospital, Wuhan, China; [e]Department of Respiratory and Critical Care Medicine, Guangyuan Central Hospital, Guangyuan, China; [f]Department of Respiratory and Critical Care Medicine, The Fourth People's Hospital of Sichuan Province, Chengdu, China; [g]Department of Neurology, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Chengdu, China

Keywords
Novel coronavirus pneumonia · Breath sounds · Auscultation · Electronic stethoscope

Abstract
Background: Effective auscultations are often hard to implement in isolation wards. To date, little is known about the characteristics of pulmonary auscultation in novel coronavirus (COVID-19) pneumonia. ***Objectives:*** The aim of this study was to explore the features and clinical significance of pulmonary auscultation in COVID-19 pneumonia using an electronic stethoscope in isolation wards. ***Methods:*** This cross-sectional, observational study was conducted among patients with laboratory-confirmed COVID-19 at Wuhan Red-Cross Hospital during the period from January 27, 2020, to February 12, 2020. Standard auscultation with an electronic stethoscope was performed and electronic recordings of breath sounds were analyzed. ***Results:*** Fifty-seven patients with average age of 60.6 years were enrolled. The most common symptoms were cough (73.7%) during auscultation. Most cases had bilateral lesions (96.4%) such as multiple ground-glass opacities (69.1%) and fibrous stripes (21.8%). High-quality auscultation recordings (98.8%) were obtained, and coarse breath sounds, wheezes, coarse crackles, fine crackles, and Velcro crackles were identified. Most cases had normal breath sounds in upper lungs, but the proportions of abnormal breath sounds increased in the basal fields where Velcro crackles were more commonly identified at the posterior chest. The presence of fine and coarse crackles detected 33/39 patients with ground-glass opacities (sensitivity 84.6% and specificity 12.5%) and 8/9 patients with consolidation (sensitivity 88.9% and specificity 15.2%), while the presence of Velcro crackles identified 16/39 pa-

Bo Wang, Yanbin Liu, Ye Wang, Wanhong Yin, Tao Liu, Dan Liu, and Diandian Li contributed equally to this work.

Fengming Luo or Gang Wang
Department of Respiratory and Critical Care Medicine
West China Hospital, Sichuan University
Chengdu, Sichuan Province 610041 (China)
fengmingluo@outlook.com or wong-gang@126.com
or
Nian Xiong
Department of Neurology, Union Hospital, Tongji Medical College
Huazhong University of Science and Technology
Wuhan 430022 (China)
nianxiong@hust.edu.cn

tients with ground-glass opacities (sensitivity 41% and specificity 81.3%). ***Conclusions:*** The abnormal breath sounds in COVID-19 pneumonia had some consistent distributive characteristics and to some extent correlated with the radiologic features. Such evidence suggests that electronic auscultation is useful to aid diagnosis and timely management of the disease. Further studies are indicated to validate the accuracy and potential clinical benefit of auscultation in detecting pulmonary abnormalities in COVID-19 infection.

Introduction

In late December 2019, large numbers of patients were diagnosed with pneumonia in Wuhan, Hubei province, China [1]. Sequencing analysis from lower respiratory tract samples indicated the presence of a novel coronavirus, now known as coronavirus 2019 (COVID-19) [2]. Infection with this virus has been associated with clusters of patients with severe respiratory disease similar to SARS. Both COVID-19 and SARS caused severe pulmonary infections requiring intensive care (ICU) admissions with high mortality [3]. Delayed diagnosis and inadequate monitoring and support may lead to severe complications. Therefore, the use of reliable and noninvasive tools would improve early diagnosis and enable better management of COVID-19-associated pneumonia.

Changes in breath sounds play an important role in the diagnosis and monitoring of respiratory diseases [4], especially for patients in isolation wards or ICUs in which changes in imaging, such as chest CT, are unavailable. While a variety of pathological conditions can be detected by auscultation, for example, pneumothorax, bronchospasm, and pulmonary edema, effective auscultation and interpretation are often hard to implement in isolation wards, wherein protected clothing and ambient noise impair clinical examination. To date, little is known about the characteristics of pulmonary auscultation in COVID-19 patients. Thus, the aim of the present study was to describe features and clinical significance of pulmonary auscultation in COVID-19 patients using an electronic stethoscope in isolation wards, which to the best of our knowledge have not been previously reported.

Methods

Subjects and Study Design

This cross-sectional, observational study was conducted among patients admitted to Wuhan Red-Cross Hospital during the period from January 27, 2020 to February 12, 2020. All patients with COVID-19 enrolled in this study were diagnosed according to the following criteria based on WHO recommendation: isolation of COVID-19 or at least 2 positive results by real-time RT-PCR assay for COVID-19 or a genetic sequence that matched COVID-19 [5]. The study protocol conforms to the principles of the Declaration of Helsinki and was approved by the Institutional Ethics Board of West China Hospital of Sichuan University (No. 2020-126). Written informed consent was collected from all patients.

Collection of Medical Records

Clinical information, including demographic data, medical history, comorbidities, symptoms, signs, laboratory findings at admission, chest CT scans, and management (i.e., oxygen support, antiviral therapy, antibiotics, and corticosteroid treatment) were obtained with data collection forms from electronic medical records of Wuhan Red-Cross Hospital. Two physicians independently reviewed the data collection forms to verify the data.

Auscultation Examination

Two physicians performed the standard auscultation within 48 h prior to CT exams. All patients with supine or lateral position were auscultated bilaterally in 3 pulmonary fields of the anterior and posterior chest (1 at the upper field, 1 at the middle field, and 1 at the basal field) in a silent environment with an electronic stethoscope (ETZ-1A[C]; Exagiga Electric, China; www.exagiga.com) directly connected to a smart phone (Huawei Technologies, Shenzhen, China) (Fig. 1). The stethoscope and the smart phone were carefully sterilized with 75% alcohol before and after each patient's auscultation. Recording time for each field included 3–4 respiratory cycles. Audio files acquired were digitized, coded, and saved as WAV files in the recorder of Android system (Google Inc., CA, USA), which were downloaded for further analyses. Adobe® Audition was used to process the obtained recordings, which were normalized and subjected to a low-pass filter (Butterworth, 1,000 Hz, fourth order) to minimize artifactual sound intrusion [4]. Recordings along with spectrograms were independently listened to and visually examined by 2 senior chest physicians. Adventitious breath sounds were defined based on the classification of the International Lung Sound Association. Briefly, wheezes are continuous and high-pitched sounds with a frequency of 100–5,000 Hz, while crackles are discontinuous, short explosive nonmusical sounds predominating during inspiration. Fine crackles are softer, shorter in duration, and higher in pitch than coarse crackles [6–8]. Velcro crackles were transient, explosive pathological lung sounds similar to the sound generated by separating the joined strip of Velcro [9]. Coarse breath sound was not included in the adventitious breath sounds of the International Lung Sound Association but was an abnormal vesicular breath sound caused by the mild edema or inflammatory infiltration of the bronchial mucosa [10]. Disagreements were resolved by discussion with a third investigator to reach a final consensus on all items.

Statistical Analysis

All continuous data were presented as mean ± SD, while categorical data were presented as count and percentages. Independent group *t* tests were used to compare means for continuous variables if the data were normally distributed; otherwise, the Mann-Whitney test was used. The specificity and sensitivity of ab-

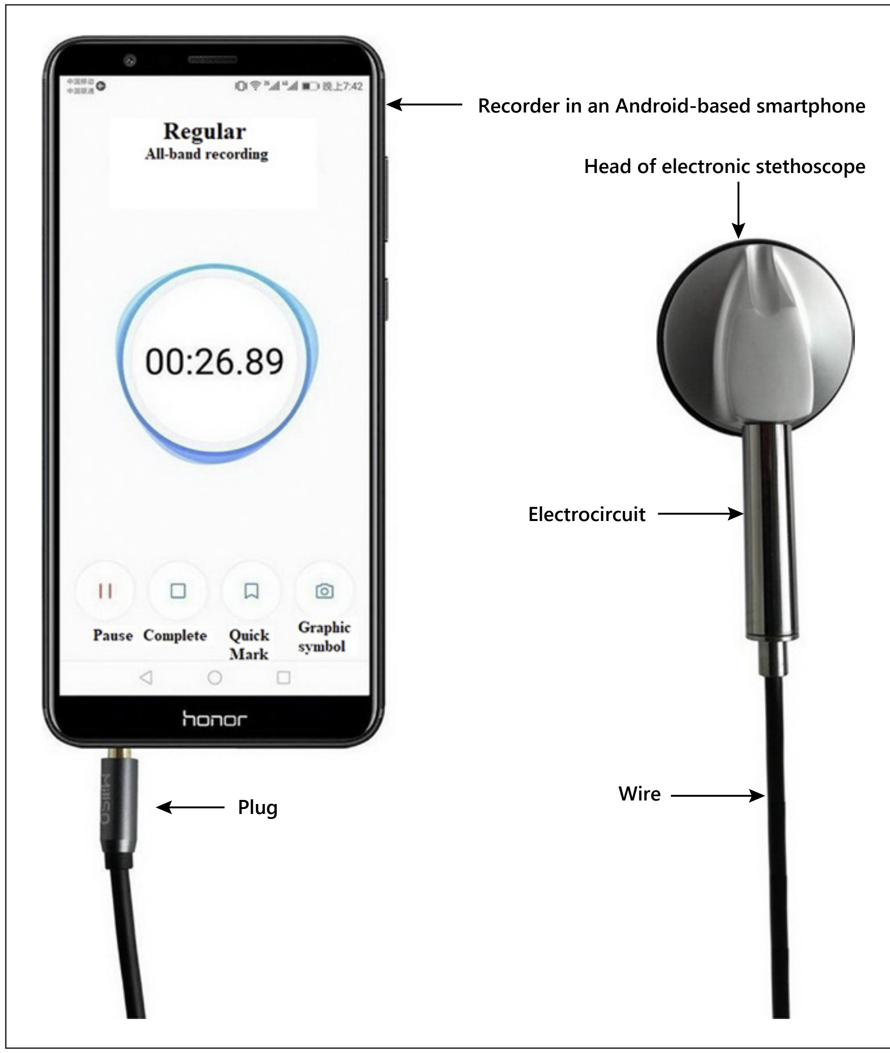

Fig. 1. The recording system employed in the present study.

normal breath sounds for identifying abnormalities on CT scans were calculated. *p* value <0.05 was considered statistically significant. All statistical analyses were performed by SPSS 25.0 for Windows (IBM, Chicago, IL, USA).

Results

Patient Characteristics

A total of 57 patients were enrolled in this study, among which 45 patients were categorized as common type and 12 patients were severe type according to Chinese guidance (Version 5). The average age was 60.6 years and 27 (47.4%) were male; 30 patients had 1 or more coexisting medical conditions, including hypertension, diabetes, cardiovascular diseases, cerebrovascular diseases, digestive diseases, and rheumatic diseases. The most common symptoms were cough (73.7%), sputum production (54.4%), and chest tightness (52.6%) during auscultation. Oxygen therapy was administered according to each patient's oxygen saturation. Invasive mechanical ventilation was required in 5.3% patients. Most patients (70.2%) were administered single or combined antibiotic therapy. Antiviral treatment (i.e., oseltamivir, arbidol, and ritonavir) was administered to 68.4% of the patients. Demographic data and baseline characteristics of the patients are summarized in Table 1.

Radiologic Features

Abnormalities in chest CT images were found in 55 patients. Most cases had bilateral lesions (53/55%, 96.4%), while only 2 patients had unilateral involvement. Typical CT findings included bilateral distribution of multiple ground-glass opacities (69.1%), fibrous stripes (21.8%),

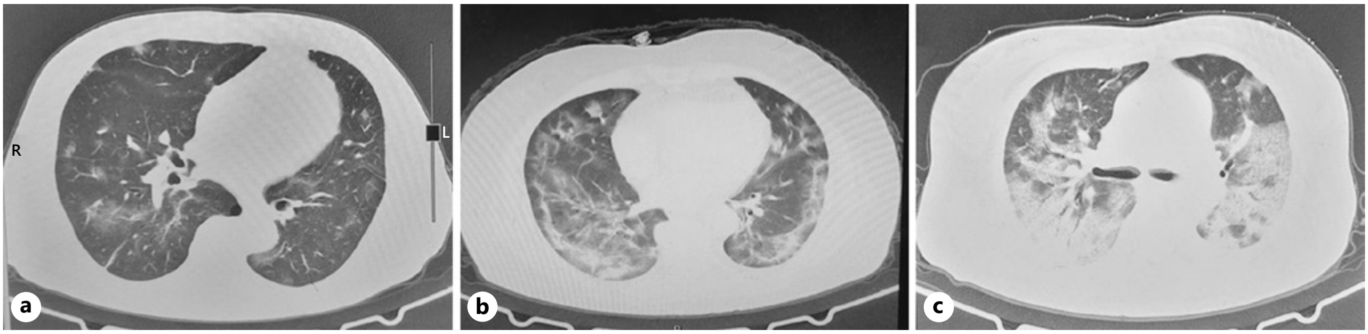

Fig. 2. Representative chest CT images at auscultation. Multiple ground-glass opacities (**a**); patchy ground glass and fibrous stripes (**b**); patchy ground glass opacities and consolidation (**c**).

Table 1. Baseline characteristics of patients infected with COVID-19

	Patients (n = 57)
Age, years	
Mean (SD)	60.6 (11.9)
Range	22–81
≤39	4 (7)
40–49	5 (8.8)
50–59	9 (15.8)
60–69	26 (45.6)
≥70	13 (22.8)
Sex, n (%)	
Male	27 (47.4)
Female	30 (52.6)
Coexisting medical conditions, n (%)	
Hypertension	17 (29.8)
Diabetes	6 (10.5)
Cardiovascular disease	5 (8.8)
Cerebrovascular disease	5 (8.8)
Digestive disease	4 (7)
Rheumatic disease	2 (3.5)
Respiratory disease	1 (1.8)
Symptoms at auscultation, n (%)	
Cough	42 (73.7)
Sputum	31 (54.4)
Chest tightness	30 (52.6)
Fatigue	21 (36.8)
Shortness of breath	9 (15.8)
Respiratory support, n (%)	
Nasal cannula	48 (84.2)
Face mask	1 (1.8)
HFNC	5 (8.8)
Non-invasive ventilation	3 (5.3)
Medications, n (%)	
Antibiotics	40 (70.2)
Antiviral treatment	39 (68.4)
Glucocorticoids	11 (19.3)

HFNC, high-flow nasal cannula oxygen therapy.

and consolidation (16.4%). Pleural effusions were detected in 13 cases (23.6%). Figure 2 shows representative chest CT images of patients with COVID-19 pneumonia.

Audiological Characteristics

Auscultation recordings (684) from 57 patients were obtained and evaluated. Electronic recordings with discontinuous current noises interfered with breath sounds and were judged to be invalid in 8 of the 684 recordings. High-quality recordings (676 or 98.8%) were used for further analyses.

Several abnormal breath sounds were identified from the recordings (Table 2), and Figure 3 illustrates spectrograms of adventitious breath sounds including wheezes, coarse crackles, fine crackles, and Velcro crackles. As shown in Table 3 and Figure 4, coarse breath sounds were the most common change in auscultation in all the 3 pulmonary fields, followed by fine and coarse crackles. Pleural friction rub was recorded in only 1 patient. The distribution of coarse breath sounds in upper, middle, and basal lungs were not significantly different, while as expected, crackles occurred more frequently in basal lungs than in the upper fields. Wheeze, on the other hand, occurred more frequently in the upper compared to the basal fields. The characteristics of pulmonary auscultation findings associated with different pulmonary fields are summarized in Figure 5. Whether auscultated at anterior or posterior chest, most cases had normal breath sounds in upper lungs (57 and 46%, respectively). However, when the sites of auscultation moved to the basal fields, the proportions of abnormal breath sounds presented in patients measured to be 78 and 70% in anterior and posterior regions of the chest, respectively. Auscultation of the anterior basal chest revealed that the proportion of coarse and fine crackles were 40%, and were higher than that of posterior basal tho-

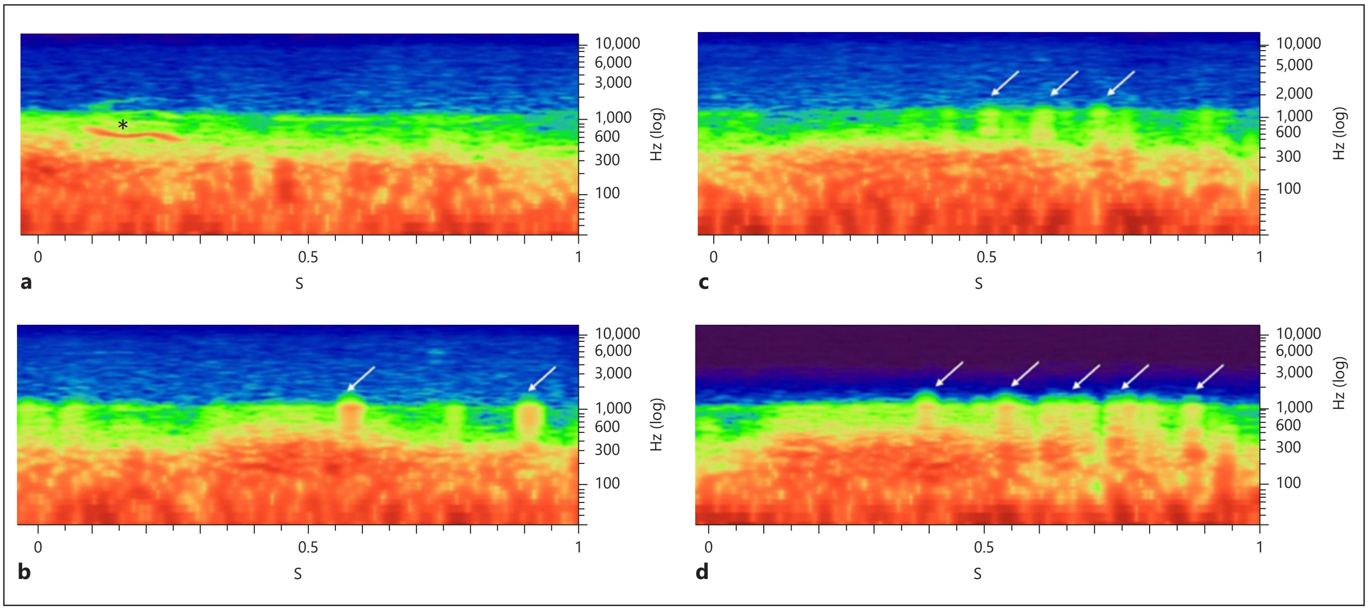

Fig. 3. Spectrograms containing adventitious breath sounds. Wheeze (**a**); coarse crackle (**b**); fine crackle (**c**); Velcro crackle (**d**). Crackles appear as vertical (arrowheads) and wheezes as horizontal (*).

Table 2. Abnormal breath sounds in patients infected with COVID-19

Abnormal breath sounds	Patients (*n* = 57)
Coarse breath sound	45 (78.9)
Wheeze	17 (29.8)
Coarse crackles	33 (57.9)
Fine crackles	40 (70.2)
Velcro crackles	19 (33.3)
Pleural friction rub	1 (1.8)

Data are presented as *n* (%).

racic auscultation (27%). Conversely, Velcro crackles were more commonly identified during basal auscultation of the posterior chest (13%) than in the anterior chest (7%).

Correlations of Auscultation with Laboratory and CT Findings

Laboratory parameters were recorded within 48 h of hospital admission and then divided into patients who were later identified with and without auscultation crackles. As shown in Table 4, although patients with fine and coarse crackles or Velcro crackles had higher levels of WBCs, neutrophils, and C-reactive protein than those without, no statistical significance was observed.

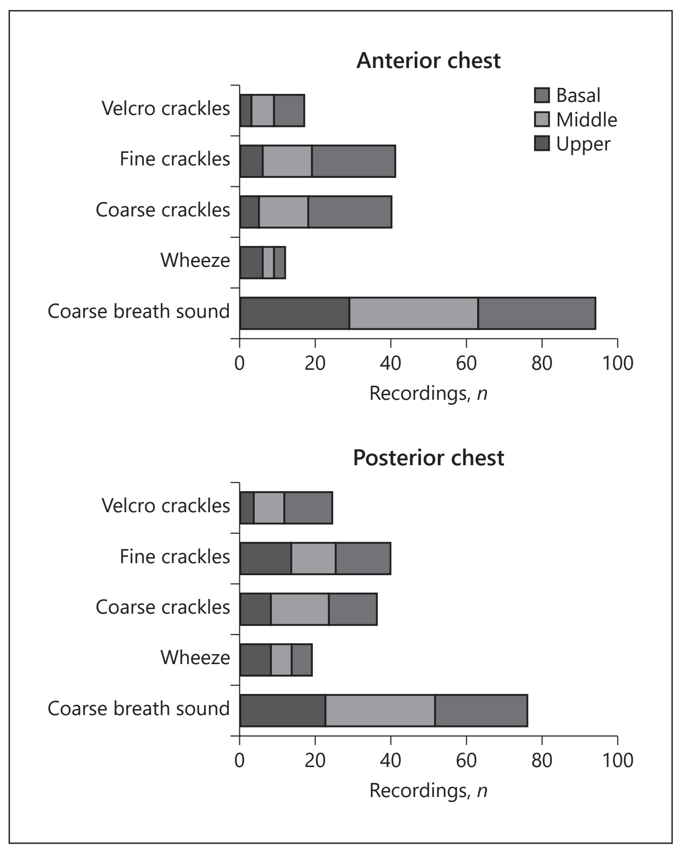

Fig. 4. Distribution of abnormal breath sounds in patients infected with COVID-19.

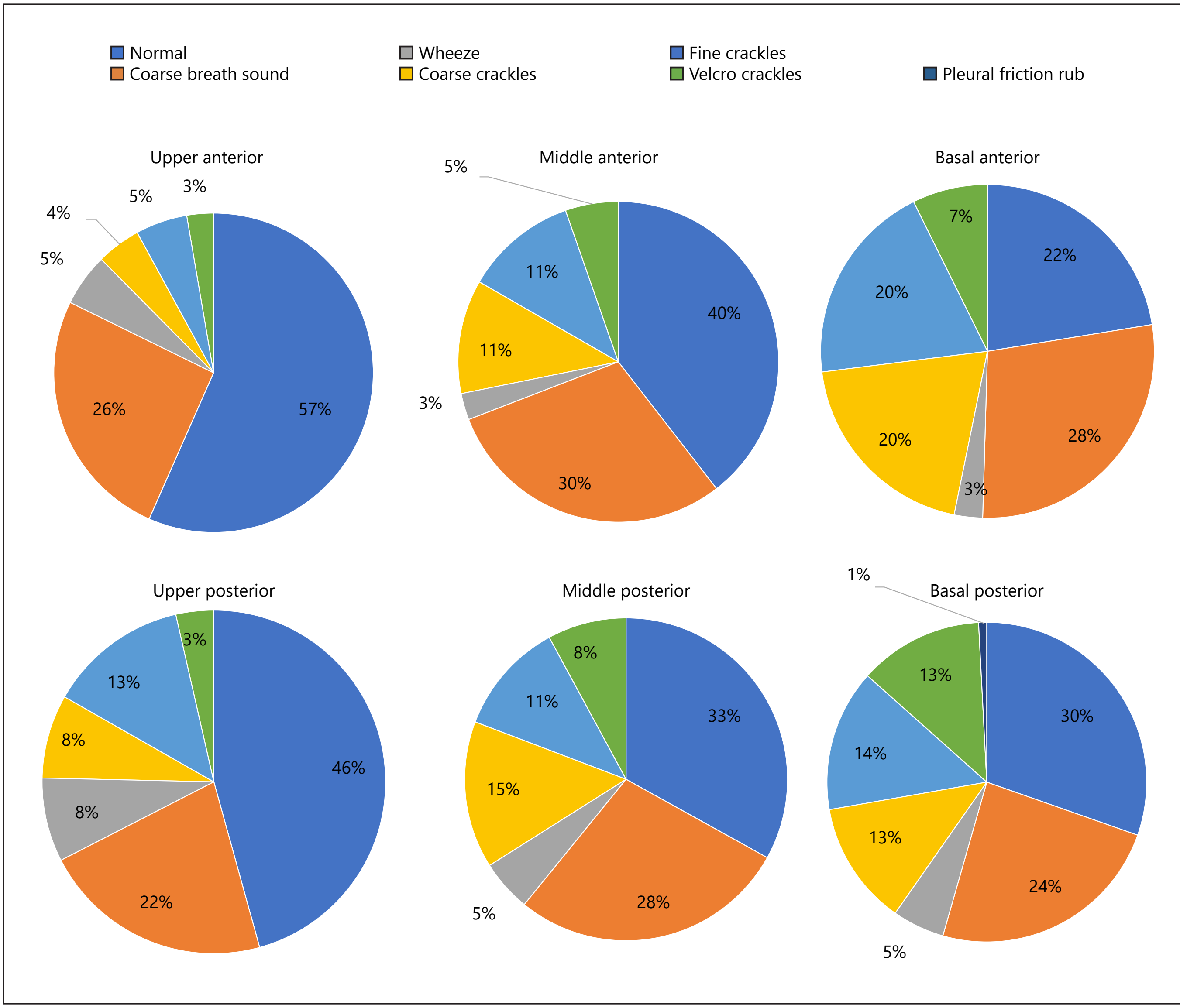

Fig. 5. Characteristics of pulmonary auscultation associated with different pulmonary fields.

We next explored the possible value of auscultation in detecting typical abnormalities on CT scans. As a result, the presence of fine and coarse crackles detected 33/39 patients with ground-glass opacities (sensitivity 84.6% and specificity 12.5%) and 8/9 patients with consolidation (sensitivity 88.9% and specificity 15.2%). Meanwhile, the presence of Velcro crackles identified 16/39 patients with ground-glass opacities (sensitivity 41% and specificity 81.3%) and 4/9 with consolidation (sensitivity 44.4% and specificity 67.4%).

Discussion

COVID-19, transmitted from person to person mainly through respiratory droplets, contact, and possibly via the fecal-oral route, has a high incidence rate and spreads rapidly, posing a great threat to global public health [1, 11, 12]. One-third of the patients were admitted to ICU [3]. Patients infected with COVID-19 often present with atypical symptoms, including fever, cough, myalgia, and fatigue [13, 14]. According to current experience, lung lesions change rapidly during the course of the disease and treatment [15]. Therefore, rapid detection of pulmonary

Table 3. Distribution of breath sounds in patients infected with COVID-19

Breath sounds	Anterior chest						Posterior chest					
	left upper (n = 57)	right upper (n = 56)	left middle (n = 57)	right middle (n = 57)	left basal (n = 57)	right basal (n = 54)	left upper (n = 57)	right upper (n = 56)	left middle (n = 57)	right middle (n = 56)	left basal n = 56)	right basal (n = 56)
Normal breath sound	33 (57.9)	31 (55.4)	22 (38.6)	23 (40.4)	12 (21)	13 (24.1)	23 (40.4)	29 (51.8)	14 (24.6)	24 (42.9)	14 (25)	20 (35.7)
Coarse breath sound	15 (26.3)	14 (25)	17 (29.8)	17 (29.8)	20 (35.1)	11 (20.4)	14 (24.6)	11 (19.7)	18 (31.6)	14 (25)	13 (23.2)	14 (25)
Wheeze	2 (3.5)	4 (7.1)	1 (1.8)	2 (3.5)	1 (1.8)	2 (3.7)	4 (7)	5 (8.9)	3 (5.3)	3 (5.4)	4 (7.1)	2 (3.6)
Coarse crackles	2 (3.5)	3 (5.3)	7 (12.3)	6 (10.5)	9 (15.8)	13 (24.1)	4 (7)	5 (8.9)	11 (19.3)	6 (10.7)	7 (12.5)	7 (12.5)
Fine crackles	4 (7)	2 (3.6)	8 (14)	5 (8.8)	10 (17.5)	12 (22.2)	10 (17.5)	5 (8.9)	4 (7)	8 (14.3)	9 (16.1)	7 (12.5)
Velcro crackles	1 (1.8)	2 (3.6)	2 (3.5)	4 (7)	5 (8.8)	3 (5.6)	3 (5.3)	1 (1.8)	8 (14)	1 (1.8)	9 (16.1)	5 (8.9)
Pleural friction rub	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1.8)

Data are presented as n (%).

Table 4. Laboratory parameters in patients with and without auscultation crackles

	Normal range	Fine and coarse crackles			Velcro crackles		
		positive (n = 49)	negative (n = 8)	p value	positive (n = 19)	negative (n = 8)	p value
WBC count, $\times 10^9$/L	3.5–9.5	6.7 (2.9)	4.5 (1.4)	0.051	7.4 (4)	5.9 (1.9)	0.132
Neutrophil count, $\times 10^9$/L	1.8–6.3	5.1 (3.2)	2.8 (1.7)	0.055	5.9 (3.9)	4 (2.4)	0.064
Lymphocyte count, $\times 10^9$/L	1.1–3.2	1.1 (0.7)	1.1 (0.3)	0.965	0.9 (0.7)	1.2 (0.6)	0.243
C-reactive protein, mg/L	<10	45.5 (43)	21.3 (23.5)	0.127	48.8 (40.5)	38.8 (42.2)	0.396

Data are presented as mean (SD).

abnormalities is an important factor in diagnosis, treatment, and isolation. While chest CT is the main tool currently used for diagnostic screening and evaluation of pulmonary disease severity, logistical problems arise when CT is applied to COVID-19 patients. Since all patients are treated in isolation, increased X-ray exposure and risk of cross-infection occurs when transferring patients needing multiple CT scans. Mechanical ventilation is usually required for support of critically ill patients, limiting the use of CT examination, delaying diagnosis and treatment decisions.

Auscultation remains an essential part of the physical examination for diagnosis of respiratory disease, providing relevant clinical information, quickly and easily [16]. Moreover, pulmonary auscultation requires minimal co-operation on the part of the patient, which is cost-effective and readily repeated as necessary. Previous studies of pulmonary auscultation demonstrated that the electronic stethoscope was found to be useful in military fight medicine, where physicians contend with noise produced by jet engines [17]. Since breath sounds can be amplified and replayed, electronic stethoscopes can be used effectively by healthcare workers wearing protective suits, which are not amenable to use of standard acoustic stethoscopes at bedside. In the present study, clear auscultation recordings were obtained from 98.8% of the patients supporting the use of the electronic stethoscope ensuring the quality of pulmonary auscultation in the isolation ward.

Present auscultation recordings demonstrated that the distribution of abnormal breath sounds in COVID-19 pneumonia had consistent characteristics. Abnormal breath sounds were in the lower lungs of most patients. Coarse breath sounds were the most common change identified during auscultation, with equivalent distributions in upper, middle, and basal pulmonary fields. Typical in early stages of bronchitis or pneumonia, the presence of coarse breath sound may help detecting early or mild pathophysiological changes of infected patients [10]. Fine and coarse crackles were identified and occurred more frequently in the lower lungs, findings consistent with the recent CT studies demonstrating patchy ground-glass opacities in subpleural chest in COVID-19 pneumonia [15, 18]. Results from the present study also suggested a good diagnostic sensitivity of fine and coarse crackles for screening patients with ground-glass opacities and consolidation on CT scans, but the low specificity indicated that these abnormal breath sounds may be insufficient to confirm the CT changes.

Velcro crackles were auscultated in several patients, being detected primarily at the posterior basal chest. Vel-

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cro crackles are proposed to aid in predicting the presence of fibrotic, interstitial lung disease patterns at HRCT and are correlated with the extent of interstitial abnormalities in the lung parenchyma. Early radiologic signs of pulmonary fibrosis, including ground glass changes and reticulation are associated with "Velcro-type" crackles [9, 19]. Consistently, in our study, the presence of Velcro crackles identified patients with ground-glass opacities with a specificity of 81.3%, which was helpful in confirming ground-glass opacities on CT scans. Since COVID-19 is considered to be somewhat similar to a SARS coronavirus, which caused varying degrees of fibrosis in both survivors and fatal cases [20], identifying the role of Velcro crackles as an early indication of pulmonary fibrosis following COVID-19 pneumonia warrants further investigation. On the other hand, the relatively low sensitivity suggested that it would not be possible to exclude ground-glass opacities when Velcro crackles were absent.

Several limitations of the present study should be addressed. First, some coexisting conditions may increase the prevalence of adventitious lung sounds. For instance, crackles heard in a patient may also result from chronic heart failure. A patient with rheumatoid arthritis was likely to have interstitial abnormalities, increasing the prevalence of Velcro crackles. Also, age and smoking status may be factors associated with adventitious sounds [21]. Second, present cross-sectional design did not allow a comprehensive characterization of the study population and final clinical outcomes. Due to the same reason, correlations between abnormal breath sounds and dynamic changes in laboratory measurements for each patient were not addressed. In addition, as patients admitted to the hospital during different disease stages, it was difficult to ensure each recording being collected at the same stage of the disease. Therefore, recordings obtained may just reflect the clinical condition when the CT imaging was performed. Also, although the assessment of the recordings was performed by physicians blinded to clinical information, the characterization of the sounds was relatively subjective.

Despite the above limitations, the present study describes common abnormalities in breath sounds and their distribution characteristics using electronic stethoscope. Our findings also imply that electronic auscultation can be readily applied at bedside in isolation wards to aid diagnosis and timely management of COVID-19 patients. Further studies with larger sample size are indicated to validate the accuracy and potential clinical benefit of auscultation in detecting pulmonary abnormalities in COVID-19 infection.

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Statement of Ethics

The study protocol conforms to the principles of the Declaration of Helsinki and was approved by the Institutional Ethics Board of West China Hospital of Sichuan University (No. 2020-126). Written informed consent was collected from all patients.

Conflict of Interest Statement

The authors declare no conflicts of interest.

Founding Sources

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Author Contributions

B.W., Y.L., and F.L. designed the study. B.W., Y.L., Y.W., W.Y., T.L., and D.L. contributed to data collection and interpretation. D.L. performed statistical analyses and drafted the manuscript. M.F., Y.Z., Z.L., Z.F., S.F., W.L., N.X., and G.W. contributed to data interpretation and critical revision of the manuscript. N.X., G.W., and F.L. take responsibility for the integrity of the work as a whole, from inception to published article.

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