

The Utility of Real-Time Remote Auscultation Using an Internet-Connected Electronic Stethoscope: An Open-Label Randomized Controlled Pilot Trial

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Abstract

Objective: This study aimed to assess the utility of real-time remote auscultation using the cardiopulmonary simulators.

Methods: In this open-label, randomized controlled trial, the researchers randomly assigned general internal medicine doctors to the real-time remote auscultation group (intervention group) or the classical auscultation group (control group). In the training session, participants listened to five different lung sounds and five cardiac sounds in a previously determined order with the correct classification. In the test session, participants had to classify the five lung sounds and five cardiac sounds in random order. For both sessions, the intervention group auscultated at a distance of 220 m, with an Internet-connected electronic stethoscope while watching the auscultation places on the computer screen. The control group performed direct auscultation using a classical stethoscope. The primary outcome was the total test score.

Results: Twenty participants were included in the study. The total test scores of lung auscultation in the intervention (86%) and control (90%) groups were not significantly different ($P = .54$). The total test score of cardiac auscultation in the control group (94%) was superior to that in the intervention group (72%, $P < .05$). Valvular diseases were not misclassified as normal sounds in real-time remote cardiac auscultation.

Discussion and Conclusions: The utility of real-time remote lung auscultation using an Internet-connected electronic stethoscope was comparable to that of classical lung auscultation. Classical cardiac auscultation was superior to real-time remote cardiac auscultation. However, real-time remote cardiac auscultation is useful for classifying valvular diseases and normal sounds.

Trial Registration: UMIN-CTR UMIN000043153; https://upload.umin.ac.jp/cgi-open-bin/ctr/ctr_view.cgi?recptno=R000049259

The date of first registration: 28/01/2021

Introduction

Telehealth has emerged as an important aspect of the medical response to the coronavirus disease 2019 (COVID-19) pandemic [1]. Telehealth can reduce the risk of infection by avoiding unnecessary contact between patients and healthcare workers [2, 3]. Until recently, medical interview using video conferencing system and message chats were the main ways to collect information from patients in telehealth. Remote auscultation is part of telehealth. Real-time remote auscultation with electronic stethoscope and an online conferencing system was reported as a very helpful tool [4].

Electronic stethoscopes are useful for real-time auscultation. An electronic stethoscope can convert acoustic sounds to electronic signals, which can be further processed and digitalized for transmission to a computer [5]. For example, if the patient is located at a site where the required diagnostic equipment is

available, healthcare workers such as nurses can gather objective measures using an electronic stethoscope and transmit this data to the healthcare providers at a distant site [6].

To the best of our knowledge, only a few previous studies have evaluated the utility of remote auscultation using an electronic stethoscope with the physician at a different location [7]. Previous studies in our laboratory have shown that the utility of Bluetooth-connected real-time remote cardiopulmonary auscultation systems is comparable to direct auscultation [8]. However, Bluetooth systems cannot allow remote auscultation at relatively distant locations. Instead, internet-connected medical systems that are based on existing wireless communication protocols can put real-time auscultation into practical use for telehealth.

On the basis of the considerations outlined in the previous section, the present study aimed to investigate the utility of real-time remote auscultation in comparison with direct auscultation in online medical care programs.

Methods

Study Design, Setting, and Participants

This study was an open-label randomized controlled trial to assess the utility of real-time remote auscultation using an electronic stethoscope and an Internet-connected online medical care program. We conducted a pilot study because the protocol for real-time remote auscultation using an Internet connection has not yet been established. We used a lung simulator for lung auscultation and a cardiology patient simulator for cardiac auscultation to ensure standardized assessment [9]. Simulators also represent a convenient, reliable, and objective method for auscultation skill assessment [10]. The simulators used in this study were located in the skills laboratory at Dokkyo Medical University, while real-time remote auscultation was conducted at the Doctor's Office of General Medicine of Dokkyo Medical University. In the control group, the participants performed direct auscultation with a classic stethoscope in the skills laboratory at Dokkyo Medical University. The straight-line distance between the skills lab and the doctor's office is approximately 220 m.

We recruited senior residents and faculty members from the Department of Diagnostic and Generalist Medicine. The exclusion criteria were refusal to participate in this study or the presence of hearing loss. The study was performed in accordance with the standards of the Declaration of Helsinki. The Institutional Ethics Committee of Dokkyo Medical University, Tochigi, Japan approved the study protocols (No. R-42-16J). This study was registered in UMIN-CTR (UMIN000043153; https://upload.umin.ac.jp/cgi-open-bin/ctr/ctr_view.cgi?recptno=R000049259). The date of first registration was 28/01/2021. Written informed consent was obtained from all participants after a detailed explanation of the study before participation.

Procedures

Study Flow and Randomization

The group allocation was conducted by using a computer-generated allocation table. Before all sessions, participants were randomly assigned to either the real-time remote auscultation group (intervention group) or the classical auscultation group (control group). After assignment to each group, the participants performed a training session, followed by a test session.

Training session

In the intervention group, participants performed real-time remote auscultation using an electronic stethoscope and an Internet-connected online medical care program. In the control group, participants auscultated all sounds directly using a classical stethoscope (3M Littmann Cardiology III), placing it on the lung simulator and the cardiac patient simulator by themselves. The participant listened to five different lung sounds and five different cardiac sounds in a previously determined order, with the correct classification provided for each sound. In the training session for lung auscultation, the following five sounds were played: normal lung sounds, wheezes, rhonchi, stridor, coarse crackles, and fine crackles. In the training session for cardiac auscultation, the following five sounds were played: normal cardiac sounds, third cardiac sound (S3 gallop enhanced), aortic stenosis, aortic regurgitation, and mitral regurgitation. Each participant was instructed to auscultate the simulators at standardized positions: two times each on the anterior and posterior sides of the lung simulator, and four times on the cardiology patient simulator (Figure 1). Each sound was played for a maximum of one minute.

Test session

In the test session, the researchers changed the settings of the cardiology patient simulator to ensure that the monitoring screen of the cardiology patient simulator displayed only a heartbeat icon. In this session, all participants auscultated the five different lung sounds and five different heart sounds from the training session in a random order and filled in the types of sounds they recognized in a formatted questionnaire (Supplemental Figure).

Simulator

For lung auscultation, the same lung simulator (MW28; Kyoto Kagaku Co., Ltd.) was used in all sessions. This simulator has been designed for medical education training using 34 samples of lung sounds, which were classified as continuous (wheezes or rhonchi) or discontinuous (fine or coarse crackles), according to the classification of the American Thoracic Society[11]. In the lung simulator, the light-emitting diode (LED) panel on the simulator side indicates the inspiration or expiration phase.

For cardiac auscultation, the same cardiology patient simulator (MW41; Kyoto Kagaku Co., Ltd.) was used in all sessions. This simulator has been designed for medical education training and includes 88 cardiac sounds recorded from actual patients and reproduced using a high-quality sound system. Cardiology patient simulators can present data for vital signs (heartbeat, blood pressure, respiratory rate, and body temperature), electrocardiogram (ECG), carotid artery pulse, jugular vein pulse, and apex cardiogram. In the test session for the control group, the cardiology patient simulator's monitoring screen was modified to display only a heartbeat icon. In the intervention group, the participants were not allowed to see the monitor.

Real-time remote auscultation

Participants auscultated all sounds remotely using an electronic stethoscope (JPES-01; MEMS CORE Co., Ltd.), a wireless module for the electronic stethoscope option (BioCMOS Co., Ltd.), a noise-canceling stereo headset (WH-1000XM3; Sony Corp.), and an online medical care program (Smart Cure, Smart Gate Inc.) (Figure 2). Researchers placed the electronic stethoscope on the simulator, and participants could monitor the placement of the electronic stethoscope in real time through the online medical care program (Figure 3).

The electronic stethoscope is equipped with an ultra-sensitive piezoelectric sensor film and an electrical amplifier, and the signals are converted into sound waves. It is also equipped with a volume regulator and a frequency filter to enable high-quality hearing. The filter has the following modes: a bell mode (20–100 Hz), diaphragm mode (200–2,000 Hz), and a wide mode (20–2,000 Hz). In the lung and cardiac parts, we used the diaphragm mode (200–2,000 Hz) and bell mode (20–100 Hz), respectively. The transmitter transferred the lung and cardiac sounds to the wireless module for the electronic stethoscope option (BioCMOS Co., Ltd) and the online medical care program via an internet connection.

The online medical care program supports full high-definition videos and 4 K still images, incorporating an online conferencing system (Cisco Webex Meetings, Cisco Systems G.K.). The online medical care program can easily share medical record information, such as medical interview sheets, sounds, and images with doctors. Therefore, in real-time auscultation, multiple doctors can simultaneously hear, record, and share data.

Data collection and Outcome Measures

We collected data on age, sex, and years since obtaining a degree in medicine from all participants as baseline demographic data. All participants' answers for each sound in the test session were collected. The primary outcome measure was the test score of each group. The secondary outcome measures were the rates of correct answers for each sound.

Statistical Analysis

Data Analysis

Results were analyzed with R 4.0.5 for Windows (The R Foundation for Statistical Computing, Vienna, Austria). A post-hoc power analysis was performed using the program G*power 3.1.9.6 (12). Statistical significance was set at $P < .05$. The correct answers in each group were compared using Fisher's exact test for primary and secondary outcome measures. Mann–Whitney U test was used to compare the continuous variables for baseline participant characteristics, which were presented as medians (IQRs). In contrast, Fisher's exact test was used to compare the categorical and binary variables for baseline participant characteristics, which were presented as numbers (percentages).

Results

Participants Profiles

Twenty physicians in the Department of Diagnostic and General Medicine at Dokkyo Medical University participated in this study (Figure 4). The median age of all participants was 32 years (IQR 7.0 years); 14 participants (70%) were male, and the median number of years since graduation was 7.5 (IQR 7.3). Ten participants each were assigned to the intervention and control groups. There were no significant intergroup differences in participant age ($P = .62$), sex ($P = .14$), and years since graduation ($P = .54$) (Table 1).

Table 1
Baseline characteristics of participants in the classical and remote auscultation groups

| Variable | Remote lung auscultation | Classical lung auscultation | <i>P</i> value |
|--|--------------------------|-----------------------------|------------------|
| | N = 10 | N = 10 | |
| Age (years), median (IQR) | 31.6 (6.5) | 32.6 (7.8) | .63 ^a |
| No. of men, n (%) | 9 (90) | 6 (60) | .15 ^b |
| Years after graduation (years), median (IQR) | 6.8 (6.7) | 8.1 (7.3) | .54 ^a |

^a Mann–Whitney U test

^b Fisher exact test.

IQR, interquartile range

Diagnostic Performance

The scores for correctly identified lung sounds are presented in Table 2. The total test score was 43/50 (86%) in the intervention group and 45/50 (90%) in the control group, with no significant differences between the groups ($P=.54$). The two groups also showed no significant differences for identification of normal lung sounds, wheezes, rhonchi, coarse crackles, or fine crackles.

Table 2
Correct identification rates of sounds

| | Remote auscultation | Classical auscultation | P value ^a |
|----------------------|---------------------|------------------------|------------------------|
| | N = 10 | N = 10 | |
| Lung sounds | | | |
| Total, n (%) | 43/50 (86) | 45/50 (90) | .54 |
| Normal | 10/10 (100) | 10/10 (100) | NA |
| Wheeze | 10/10 (100) | 9/10 (90) | .99 |
| Rhonchi | 9/10 (90) | 9/10 (90) | NA |
| Fine crackles | 6/10 (60) | 8/10 (80) | .34 |
| Coarse crackles | 8/10 (80) | 9/10 (90) | .54 |
| Cardiac sounds | | | |
| Total, n (%) | 36/50 (72) | 47/50 (94) | <.05 |
| Normal | 9/10 (90) | 10/10 (100) | .99 |
| S3 gallop | 8/10 (80) | 10/10 (100) | .99 |
| Aortic stenosis | 5/10 (50) | 9/10 (90) | .07 |
| Aortic regurgitation | 7/10 (70) | 9/10 (90) | .28 |
| Mitral regurgitation | 7/10 (70) | 9/10 (90) | .28 |

^a Fisher's exact test.

The participants' responses during lung auscultation are described in more detail in Table 3. The exploratory analysis showed that the participants in the intervention group did not assign abnormal lung sounds to normal lung sounds.

Table 3
Detailed answers in lung auscultation

| Participants' responses in the remote auscultation group | | | | | |
|--|--------|---------|---------|-----------------|---------------|
| | Normal | Wheezes | Rhonchi | Coarse crackles | Fine crackles |
| Correct answer | | | | | |
| Normal | 10/10 | 0 | 0 | 0 | 0 |
| Wheezes | 0 | 10/10 | 0 | 0 | 0 |
| Rhonchi | 0 | 0 | 9/10 | 0 | 1/10 |
| Coarse crackles | 0 | 0 | 0 | 8/10 | 2/10 |
| Fine crackles | 0 | 0 | 1/10 | 3/10 | 6/10 |
| Participants' responses in the classical auscultation group | | | | | |
| | Normal | Wheezes | Rhonchi | Coarse Crackles | Fine Crackles |
| Correct answer | | | | | |
| Normal | 10/10 | 0 | 0 | 0 | 0 |
| Wheezes | 0 | 9/10 | 1/10 | 0 | 0 |
| Rhonchi | 0 | 1/10 | 9/10 | 0 | 0 |
| Coarse crackles | 0 | 0 | 0 | 9/10 | 1/10 |
| Fine crackles | 1/10 | 0 | 0 | 1/10 | 8/10 |

The correctly identified cardiac sounds are presented in Table 2. The total test score was 36/50 (72%) in the intervention group and 47/50 (94%) in the control group, with a significant difference between groups ($P < .05$). Only 5/10 (50%) participants in the intervention group correctly auscultated aortic stenosis, compared to 9/10 (90%) in the control group ($P = .07$). Seven out of 10 (70%) participants in the intervention group correctly auscultated aortic regurgitation and mitral regurgitation, whereas 9/10 (90%) in the control group did ($P = .28$).

Details of the participant responses in cardiac auscultation are listed in Table 4. In the exploratory analysis, participants in both groups showed no misclassifications between normal cardiac sounds and the sounds of valvular diseases (aortic stenosis, aortic regurgitation, and mitral regurgitation). In the intervention group, aortic stenosis was assigned as aortic regurgitation by 3/10 (30%) participants and as mitral regurgitation by 2/10 (20%) participants. On the other hand, aortic regurgitation was assigned as aortic stenosis by 2/10 (20%) participants, and mitral regurgitation was assigned as aortic stenosis by 3/10 (30%) participants.

Table 4
Details of answers in the cardiac auscultation

| Participants' answers in the remote auscultation group | | | | | |
|---|--------|-----------|-----------------|----------------------|----------------------|
| | Normal | S3 gallop | Aortic stenosis | Aortic regurgitation | Mitral regurgitation |
| Correct answer | | | | | |
| Normal | 9/10 | 1/10 | 0 | 0 | 0 |
| S3 gallop | 2/10 | 8/10 | 0 | 0 | 0 |
| Aortic stenosis | 0 | 0 | 5/10 | 3/10 | 2/10 |
| Aortic regurgitation | 0 | 1/10 | 2/10 | 7/10 | 0 |
| Mitral regurgitation | 0 | 0 | 3/10 | 0 | 7/10 |
| Participants' answers in the classical auscultation group | | | | | |
| | Normal | S3 gallop | Aortic stenosis | Aortic regurgitation | Mitral regurgitation |
| Correct answer | | | | | |
| Normal | 10/10 | 0 | 0 | 0 | 0 |
| S3 gallop | 0 | 10/10 | 0 | 0 | 0 |
| Aortic stenosis | 0 | 0 | 9/10 | 1/10 | 0 |
| Aortic regurgitation | 0 | 0 | 1/10 | 9/10 | 0 |
| Mitral regurgitation | 0 | 0 | 1/10 | 0 | 9/10 |
| Supplemental Figure. Questionnaire format for the identification of the five lung sounds and five cardiac sounds. | | | | | |

Post-hoc power analysis revealed that the statistical power for comparison of the total test score in the lung part was 0.2 between the intervention group and the control group. However, the corresponding value in the cardiac part exceeded 0.99.

Discussion

Principal Results

This study yielded three main findings. First, using a simulator, we have scientifically demonstrated that the usefulness of real-time remote lung auscultation with an internet-connected electronic stethoscope

was comparable to direct auscultation using a classical stethoscope. In lung auscultation, coarse and fine crackles are helpful in diagnosing pneumonia[13]. The results of this study suggest that real-time remote auscultation is helpful in the diagnosis of pneumonia. The ability to detect this finding by remote auscultation will have a significant impact on clinical practice in the context of the global spread of COVID-19, since in an outpatient department, during ward rounds, or in a doctor's visit at home for febrile patients, medical staff can screen the patients' lung sounds without contact and protect themselves from infectious diseases including COVID-19.

The second major finding was that in cardiac auscultation, classical auscultation was superior to real-time remote auscultation using an Internet-connected electronic stethoscope. This could be attributed to the differences in sound quality caused by the Internet connection and the difficulties in detecting the systole and diastole phases. However, valvular diseases were not misclassified as normal cardiac sounds in real-time remote auscultation. Moreover, normal cardiac sounds were not misclassified as valvular diseases. These results suggest that real-time remote cardiac auscultation may still be useful in identifying whether a cardiac sound is normal or related to a valvular disease, indicating the potential of this technique in facilitating remote screening.

The third major finding of the study was that half of the aortic stenosis cases were misclassified as other valvular diseases in real-time remote cardiac auscultation. This finding suggests that real-time remote cardiac auscultation cannot easily classify the type of valvular disease. This could be attributed to the difficulty in determining the phase of abnormal cardiac sounds (systole or diastole) without palpating pulses and the discerning the area of cardiac sound conduction or transmission.

Strengths

This study had three major strengths. First, this study demonstrated the utility of an Internet-connected real-time remote lung auscultation system. Real-time remote cardiac auscultation may help distinguish between normal sounds and the sounds of valvular diseases. Second, all the physicians who participated in the study were general internal medicine physicians, who routinely use stethoscopes to screen for abnormal auscultation findings. Third, the survey items in this study evaluated five common lung sounds and five common cardiac sounds that are often encountered in actual clinical practice[14, 15].

Limitations

This was a pilot study with four major limitations. First, the sample size was small and did not include data from actual patients. Fully powered trials are required to show equivalence or non-inferiority, especially for the lung auscultation part. Therefore, future studies with larger sample sizes are required to confirm the utility of real-time auscultation in real clinical settings. Second, the responses may have shown some within-participant dependencies. Third, participants in the intervention group could not decide on the timing of the changes in the auscultation sites, while the participants in the control group could change the auscultation sites by themselves, making it easier to detect the systole and diastole phases in classical cardiac auscultation. Fourth, the electronic stethoscope made the noises more

pronounced through the Internet connection. This characteristic affected the classification of cardiac valvular diseases in the intervention group.

Comparison with Prior Work

To the best of our knowledge, no previous study has directly compared real-time remote auscultation using an Internet connection with classical auscultation. Our laboratory has already conducted a study directly comparing real-time remote auscultation using a Bluetooth connection with classical auscultation, demonstrating the utility of real-time lung and cardiac auscultation using a Bluetooth connection[8]. These results indicate the effectiveness of real-time remote lung auscultation using both Bluetooth and Internet connections. In our previous study, the total cardiac sound score was 50/60 (83.3%) in the Bluetooth-connected real-time remote auscultation group and 119/140 (85.0%) in the control group, with no difference between the two groups. The results obtained with real-time remote cardiac auscultation using an Internet connection were poorer than those obtained with remote auscultation based on a Bluetooth connection. This could be because participants could easily distinguish between inspiratory and expiratory phases in normal lung sounds even in real-time lung auscultation. However, it would be difficult to distinguish between the systolic and diastolic phases in real-time cardiac auscultation only from the quality of cardiac sounds.

Conclusions

This study demonstrates that the utility of an Internet-connected real-time remote lung auscultation system is comparable to that of classical auscultation. Internet-connected real-time remote cardiac auscultation can distinguish between normal sounds and the sounds of valvular diseases. It will be necessary to develop additional tools to improve real-time remote cardiac auscultation in future studies. For example, a phonocardiogram or real-time ECG can visualize the systole and diastole phases of sounds[16]. Artificial intelligence can also be used to automatically support clinicians in diagnosing cardiopulmonary diseases[17]. The findings of this study can thus pave the way for future studies of real patients with fully powered trials.

Declarations

Acknowledgements

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Authorship confirmation statement

Contributors: TI, TH, YH, KI, SK, TS contributed to the study concept and design. TI, TH and YH performed the statistical analysis. TI, and TH contributed to the drafting of the manuscript. YH, KI, SK and TS contributed to the critical revision of the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

An electronic stethoscope (JPES-01, MEMS CORE Co., Ltd.) used in this study was provided by the MEMS CORE, Miyagi, Japan. An online medical care program (SMART CURE, SMART GATE Co., Ltd.) used in this study was provided by the SMART GATE, Tokyo, Japan. Except for the Dokkyo Medical Education & Research Foundation, the electronic stethoscope, and the online medical care program, all other authors have no conflict of interest.

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Figures

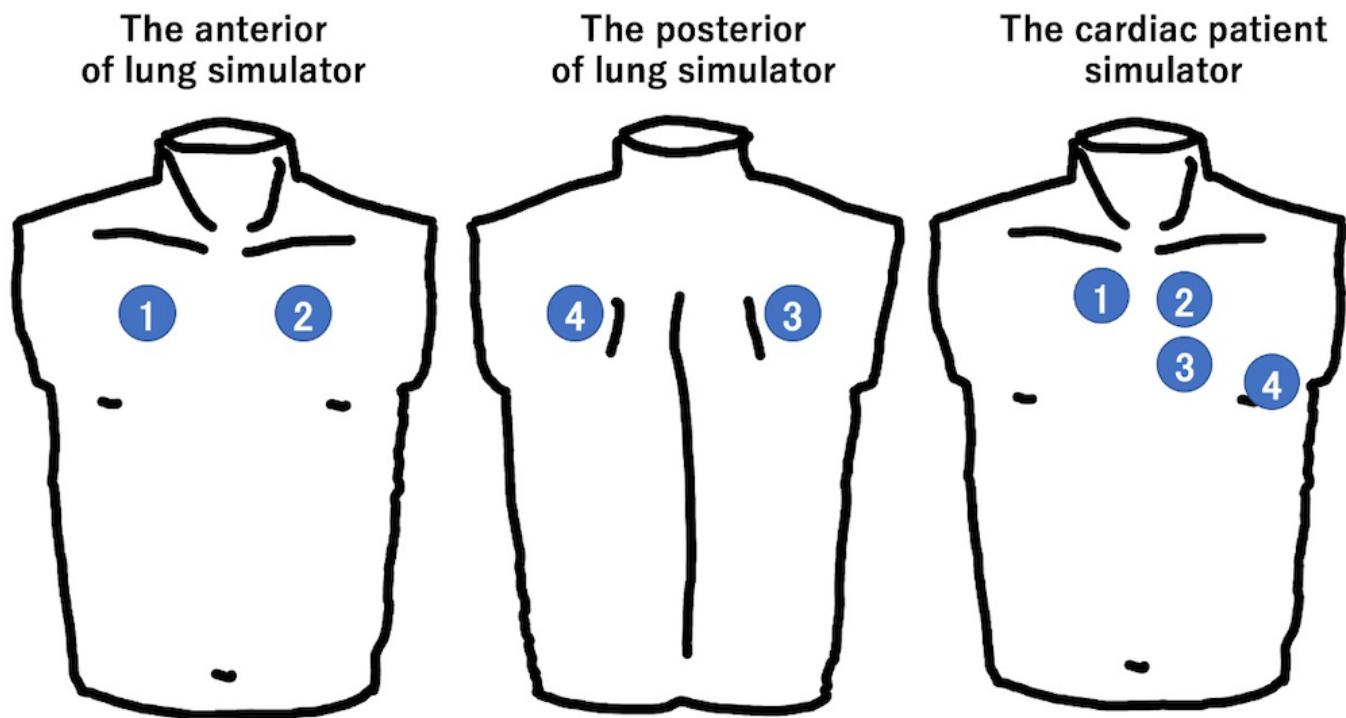


Figure 1

The four different areas of auscultation on the lung and the cardiology patient simulator.



Figure 2

Remote auscultation equipment at the researcher site (A) and the participant site (B), including an electronic stethoscope, a wireless module for electronic stethoscope option, and a noise-canceling stereo headset.

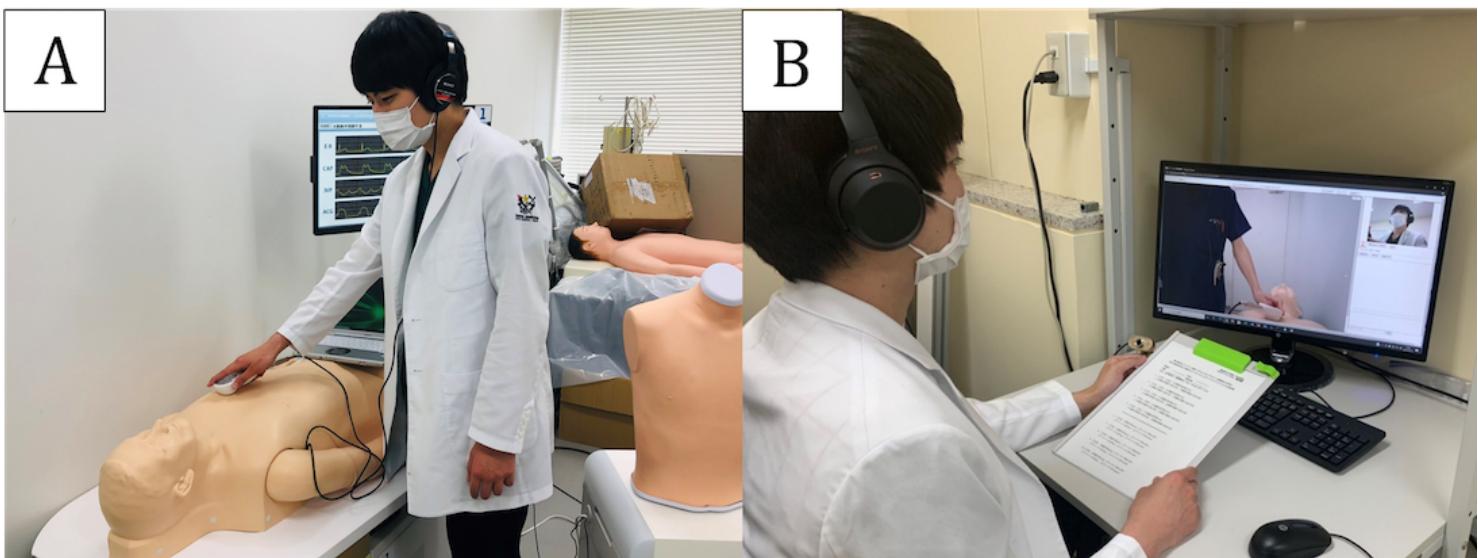


Figure 3

The Internet-connected real-time remote auscultation processes. The researcher put an electronic stethoscope on the simulator (A). The participant remotely auscultates the sound with an internet-connected medical system (B).

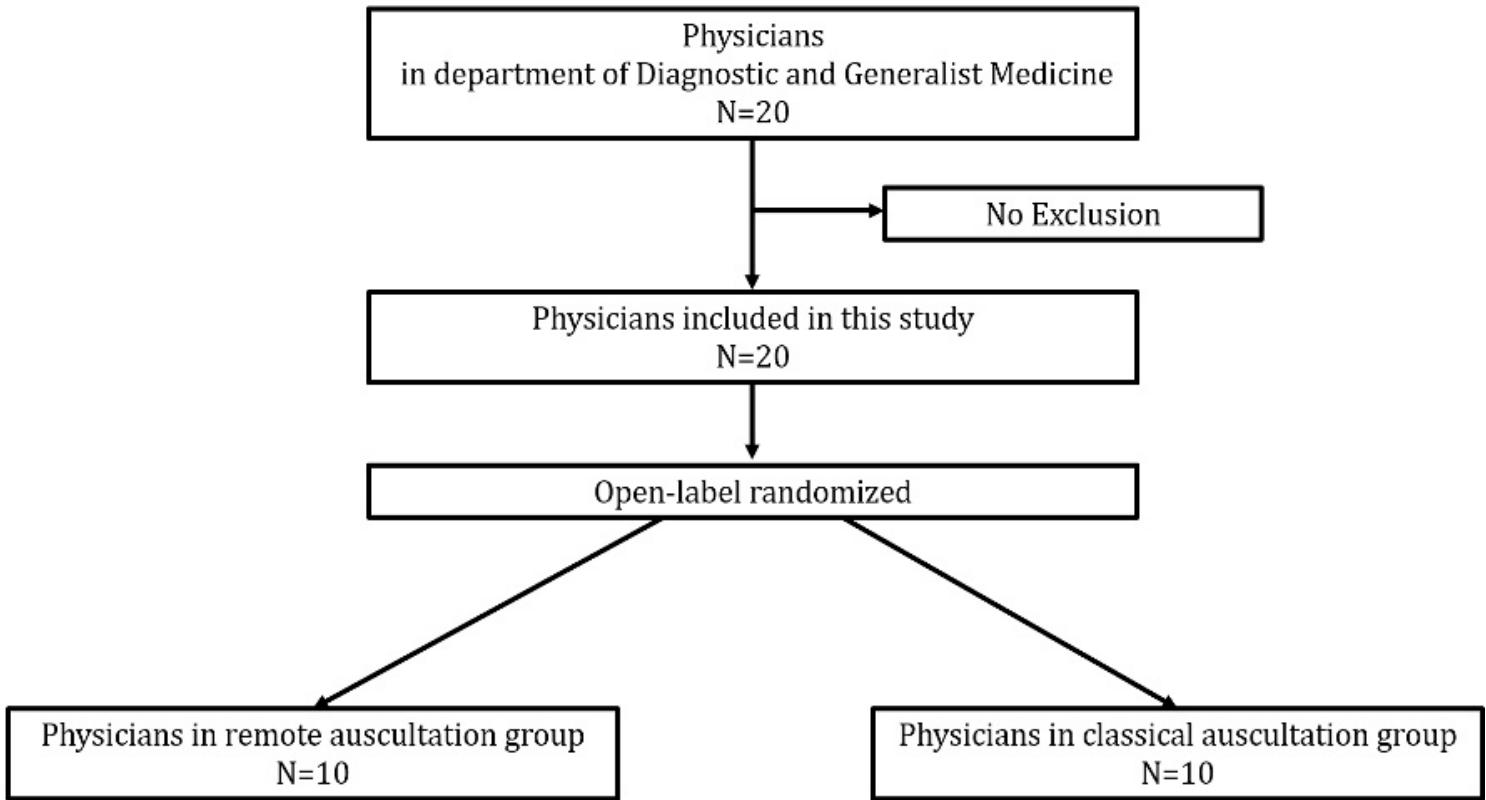


Figure 4

Flowchart of participants in the study. Supplemental Figure. Questionnaire format for the identification of the five lung sounds and five cardiac sounds.

Supplementary Files

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