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ORIGINAL ARTICLE

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Wireless stethoscope for auscultation of the heart and lungs in critically ill patients: a systematic review

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ABSTRACT

Introduction: Examining the heart and lungs is necessary for critically ill patients, as these individuals may have abnormalities with either or both of these organs. This review systematically determined how the auscultation of the heart and lungs using a wireless stethoscope affected the results.

Methods: The research design used was a systematic review following preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. Databases were searched using the search terms “auscultation," "critical patients," and "stethoscope wireless” and associated MeSH terms. The abstracts of the selected articles were examined independently by two researchers. A systematic search was conducted through several databases (Scopus, PubMed, JSTOR, and Springer-link), which were published from July 2012 to July 2022 .After reading the full content of the included studies, key themes and concepts were extracted and synthesized.

Results: In total 142 articles were screened. Five articles met the inclusion criteria and were analyzed. The analysis revealed that wireless stethoscopes have increased sensitivity with indicators capable of diagnosing abnormal auscultation results in patients who have abnormal aucultation results on the gold standard. Three out of five studies suggested that the auscultation of the heart and lungs by wireless stethoscopes are more sensitive, while two other studies stated that wireless stethoscopes have the same sensitivity as manual acoustic stethoscopes.

Conclusions: Based on this systematic review, a wireless stethoscope may be more sensitive than an acoustic one. Nevertheless, due to limited studies, a more well-controlled human study is warranted to be done.

Keywords: auscultation, critical patient, stethoscope wireless

Introduction

Technological advances are currently growing very rapidly in all fields, including the health sector, which affects both patients and health workers. Technological advancements in the health sector, particularly medical devices, are needed by health workers because those devices play a pivotal role in supporting their work (Tian et al., 2019). Since its first invention, the stethoscope has undergone some transformative improvements, including the introduction of electronic systems in the last two decades. Improvement in technology has led to the advancement of electronic stethoscope design that dramatically reduces external noise contamination through hardware redesign and dynamic signal processing (McLane et al., 2021).

A stethoscope is a typical medical acoustic equipment used to listen to the noise in the human body, making it one of the most important tools used by nurses and other healthcare professionals (Qu et al., 2021). Stethoscopes are considered one of the most valuable medical devices because they are non-invasive, real-time, and provide informative information (Sarkar et al., 2015). In professional healthcare, nurses frequently use stethoscopes to assist the voice or auscultate both when listening to heart sounds, lungs, and systolic and diastolic pressures, thus, making the stethoscope an indispensable tool in carrying out its work (Pratiwi et al., 2021).

Patient monitoring has evolved over the years, including critically ill patients, from the use of monitors to the development of devices that can be used to monitor patients, especially monitoring the patient's vital signs, to check whether their health is normal or deteriorating for some time (Barnett et al., 2022). In addition to monitoring vital signs, finding the cause of decreased vital signs must be done by carrying out a physical examination of these vital organs, one of which is by auscultation. The critical patient is physiologically unstable patient and experiences dysfunctional disorder, namely multi-organ failure, and his survival depends on sophisticated therapy and monitoring tools. In addition, In addition, critical patients have changes in physiological function which affect vital signs and these changes can get worse at any time so this situation can be life-threatening (Saketkoo et al., 2021).

One of the physical examinations that must be carried out by nurses in critical patients is by carrying out auscultation of the heart and lungs to find out any abnormalities in these organs (Harcharran, 2022). Abnormal sounds that are usually heard when auscultating the lungs in critical patients, namely wheezes, stridor, crackles while on auscultation of the heart, friction rub and gallop, although not all critical patients have these sounds (Mehmood et al., 2014). Poor auscultation results can affect the accuracy in carrying out care and treatment so that the treatment of patients is not optimal and causes lengthy treatment (Hu et al., 2017).

Factors that can improve the quality of auscultation, namely the use of a stethoscope that has a good level of sensitivity as well as the use of a more flexible stethoscope can assist nurses in carrying out auscultation, especially in critical patients because such patients often have other tools in their bodies that interfere with the auscultation process (Goldsworthy et al., 2021). Stethoscopes have experienced better development starting from the use of wireless which can help stethoscopes become more flexible, this is because there is no dangling tubing which limits auscultation (Andrès et al., 2018; Swarup & Makaryus, 2018).

Some studies have compared acoustic and wireless stethoscopes in clinical settings. Wireless stethoscopes were compared with standard stethoscopes and concluded that acoustic stethoscopes were preferred. However, they suggested that an ideal stethoscope would combine the advantages of both acoustic and wireless stethoscopes (Høyte et al., 2005; Iversen et al., 2006).

Wireless stethoscope is a solution to solve the problem of remote auscultation (Perri, 2010). Additionally, wireless stethoscopes have another advantage over classic stethoscopes, namely that they can increase the sound produced (A-Mohannadi et al., 2022); and contribute to better performance on auscultation, as personalized adjustments can be made (Høyte et al., 2005b). They cannot, however, be used in noisy environments because wireless stethoscopes are very sensitive to sound waves. However, there is limited evidence that compares the sensitivity of wireless stethoscopes for diagnostic purposes with an acoustic stethoscope. Thus, this review systematically assessed studies investigating the sensitivity of using a wireless stethoscope compared to acoustic wireless in critically ill patients.

Materials and Methods

This systematic review was conducted by the PRISMA guidelines (Page et al., 2021). Systematic reviews can facilitate the critical roles in providing a synthesis of knowledge statements and addressing answered phenomena.

Search strategy

We conducted an exploration of the title and abstract in four databases: Scopus, PubMed, JSTOR, and Springer-link. Articles published from July 2012 to July 2022 were searched using a comprehensive search strategy. We constructed the search keywords in this systematic review based on PICOS (Patient, Intervention, Control, Outcome, and Study Design). In this review, the subject was a critically ill patient; the study used a digital wireless stethoscope, compared wireless stethoscopes and acoustic stethoscopes, and the outcome was sensitivity in determining auscultation for diagnostics. Therefore, we used several main keywords such as (stethoscope wireless OR digital stethoscope) AND (auscultation) AND (critical ill OR critical patients). A complete search can be found in Supplementary Table 3.

Inclusion and exclusion criteria

The inclusion criteria were full paper articles with quantitative research methods comparing the sensitivity of wireless stethoscopes and acoustic stethoscopes. The

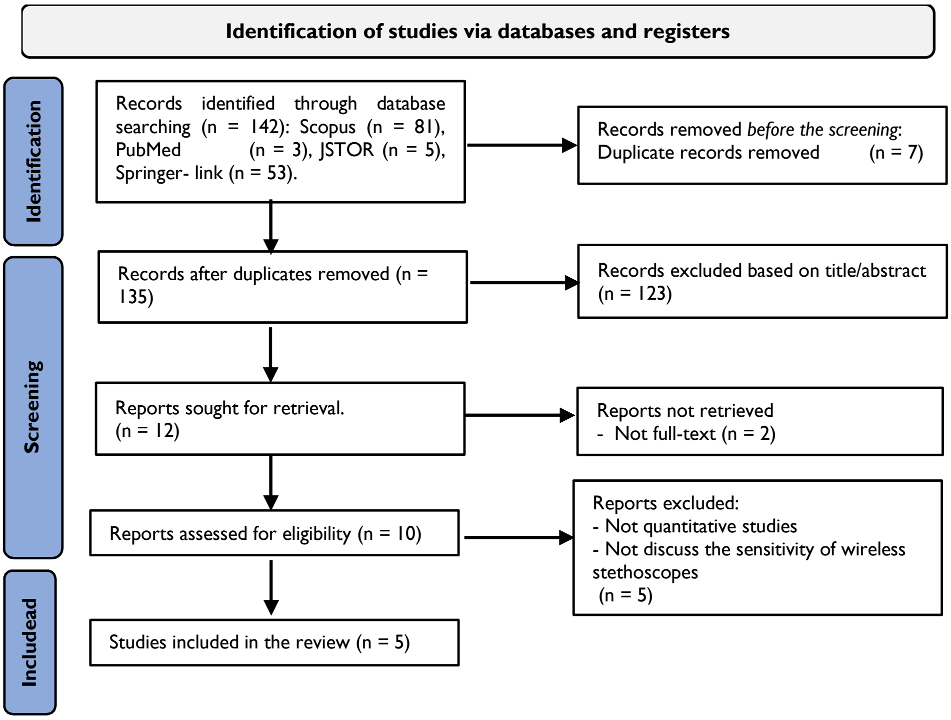

Figure 1 Prisma diagram of the systematic data searching and extraction

exclusion criteria in this study were non-quantitative studies, the articles were not full text and were not published in English.

Search outcomes

A total of 142 potentially relevant articles were initially identified in the four databases. A total of 135 of those remained after duplications were removed using Endnote software. Next, the titles and abstracts of those articles were read one by one for further screening, after which the remaining 10 full-text articles were further assessed for eligibility. Subsequently, five of those articles were excluded for various reasons (i.e., did not compare the sensitivity of wireless stethoscopes and was not tested by health workers). Finally, five studies were deemed eligible for inclusion in this review (Figure 1). The study selection process was carried out by two of this study's authors (RP and SI) independently, after which they reached an agreement. There was no disagreement between the two authors during the selection process.

Assessment of methodological quality

The methodological quality of the articles was assessed using the JBI Critical Assessment Checklist guidelines. The instruments used consist of two types which are adjusted based on the research design according to the screening in this screening system. The instruments were the JBI Critical Appraisal Checklist for Randomized Controlled Trial Studies which consists of 13 questions, and the JBI Critical Appraisal Checklist for Analytical Cross-Sectional Studies which consists of eight questions. The JBI Critical Assessment Checklist is an instrument used to assess the methodological quality of

Table 1. Quality assessment for RCT studies

Authors	**Checklist criteria for RCT studies**												
	1	2	3	4	5	6	7	8	9	10	11	12	13
(Kalinauskienė et al., 2019)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
(Hirosawa et al., 2021b)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
(Gottlieb et al., 2018)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
(Islam et al., 2019)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Y = yes; N = no; U = unclear. 1. Was true randomization used for assignment of participants to treatment groups? 2. Was allocation to treatment groups concealed? 3. Were treatment groups similar at the baseline? 4. Were participants blind to treatment assignment? 5. Were those delivering treatment blind to treatment assignment? 6. Were outcomes assessors blind to treatment assignment? 7. Were treatment groups treated identically other than the intervention of interest? 8. Was follow up complete and if not, were differences between groups in terms of their follow up adequately described and analyzed? 9. Were participants analyzed in the groups to which they were randomized? 10. Were outcomes measured in the same way for treatment groups? 11. Were outcomes measured in a reliable way? 12. Was appropriate statistical analysis used? 13. Was the trial design appropriate, and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?

Table 2 Quality assessment for cross-sectional studies

Authors	Checklist criteria for cross-sectional studies							
	1	2	3	4	5	6	7	8
(Zhang et al., 2021)	Y	Y	Y	Y	Y	Y	Y	Y

Y = yes; N = no; U = unclear. 1.Were the criteria for inclusion in the sample clearly defined? 2.Were the study subjects and the setting described in detail? 3.Was the exposure measured in a valid and reliable way? 4.Were objective, standard criteria used for measurement of the condition? 5.Were confounding factors identified? 6.Were strategies to deal with confounding factors stated? 7.Were the outcomes measured in a valid and reliable way? 8.Was appropriate statistical analysis used?

a study and to assess the extent to which the review has addressed possible biases in its design, intervention, and analysis.

Data extraction and synthesis

Two authors (RP and SI) independently extracted data from all of the included studies into Excel spreadsheets. Any disagreements during the data extraction process were resolved through un-blinded discussion. The authors extracted data into five main categories: (a) study information including the author(s), year of publication, and study country; (b) populations; (c) research design; (d) measurements; and (e) findings. Narrative synthesis was applied to analyze and explain the findings in this study (Popay et al., 2006). The process included listing data for the included studies, identifying the type of study being performed, and displaying the sensitivity results of the wireless stethoscope.

Results

Characteristics of included studies

The number of participants in those studies ranged from 30 to 60. Two of the studies were conducted in the United States of America (Gottlieb et al., 2018; Kalinauskienė et al., 2019), one in Japan (Hirosawa et al., 2021), one in China (Zhang et al., 2021), and one in Bangladesh (Islam et al., 2019). Four of the studies collected their data using randomized controlled trial design (Gottlieb et al., 2018; Hirosawa et al., 2021; Islam et al., 2019; Kalinauskienė et al., 2019), and one used a cross-sectional design (Zhang et al., 2021). All studies compared wireless stethoscopes to the gold standard for sensitivity (Gottlieb et al., 2018; Hirosawa et al.,

Table 3 Summary of articles included in the systematic review

Authors, year, country	Population	Research Design	Type of wireless stethoscopes	Findings
Kalinauskiene et al. (2019) USA	Patients with body mass index >30 kg/m^2 (obese), were older than 18 years, were referred for an echocardiogram, and agreed to participate in the study.	Randomized Controlled Trial (RCT)	Compare the 3M Littmann 3200 Electronic Stethoscope and 3M Littman Cardiology III Mechanical Stethoscope	Wireless stethoscopes have a higher sensitivity value than acoustic stethoscopes, namely 60.1% vs 45.7%, p<0.0001.
Zhang et al. (2021) China	Patients with SARS-CoV-2 Pneumonia.	Cross-sectional	Assessing a wireless stethoscope in critically ill patients with SARS-CoV-2 pneumonia	There was no significant difference between the traditional acoustic stethoscope and the stethoscope for lung and heart auscultation. However, the stemoscope used in this study is easy and comfortable to use.
Hirosawa et al. (2021) Japan	Senior residents and faculty in the department of general internal medicine of a university hospital.	Randomized Controlled Trial (RCT)	Compare the electronic stethoscope wireless and traditional stethoscope	A listening system using a Bluetooth-connected electronic stethoscope has comparable results to listening with a traditional stethoscope; other than that the total combined test score was 80/110 (72.7%) in the intervention group and 71/90 (78.9%) in the control group, with no differences between the groups (P=.32).
Gottlieb et al. (2018) USA	Internal medicine resident participants were randomly selected to hear either the analog or electronic lung sounds.	Randomized Controlled Trial (RCT)	Compare the electronic stethoscope wireless and analog stethoscope	There was no significant difference in overall auscultation scores of lung sounds using analog and electronic stethoscopes.
Islam et al. (2019) Bangladesh	Pediatric patients who have abnormal and normal heart sounds.	Randomized Controlled Trial (RCT)	Assessing pediatric patients with abnormal and normal heart sounds using the Wireless Electronic Stethoscope	There is an increase in the sensitivity of the wireless stethoscope and has high accuracy. Stethoscopes have a sensitivity value of 95 (12%).

2021; Islam et al., 2019; Kalinauskienė et al., 2019; Zhang et al., 2021)

Type of wireless stethoscope sensitivity

All data collection techniques were performed by comparing the wireless stethoscope auscultation results with the gold standard. Several types of stethoscopes were found that had been designed using a wireless network (Gottlieb et al., 2018; Hirosawa et al., 2021; Islam et al., 2019; Zhang et al., 2021), while another study used a 3M Littmann 3200 Electronic Stethoscope connected wirelessly (Kalinauskienė et al., 2019). All studies were tested by experts, namely: internal medicine (Gottlieb et al., 2018; Hirosawa et al., 2021; Zhang et al., 2021), cardiologist (Kalinauskienė et al., 2019), and pediatrician Islam et al., 2019).

Outcomes

Three out of five studies stated that auscultation of the heart and lungs using a wireless stethoscope was more sensitive, this is because wireless stethoscopes are very sensitive to sound waves and have features that can amplify sound volume compared to acoustic stethoscopes (Hirosawa et al., 2021; Islam et al., 2019; Kalinauskienė et al., 2019), whereas two other studies suggested that wireless stethoscopes have the same sensitivity as acoustic stethoscopes (Gottlieb et al., 2018; Zhang et al., 2021).

Wireless stethoscopes have a higher sensitivity value than acoustic stethoscopes, namely (60.1% vs 45.7% , $p < 0.0001$) (Kalinauskienė et al., 2019), while other studies state that wireless stethoscopes have a sensitivity value of 95.12% (Islam et al., 2019), other than that the total combined test score was 80/110 (72.7%) in the intervention group and 71/90 (78.9%) in the control group, with no differences between the groups ($P=.32$) on wireless stethoscope testing (Hirosawa et al., 2021). Two other studies state that wireless stethoscopes and acoustic stethoscopes do not have a significant difference in value for listening to heart and lung sounds (Gottlieb et al., 2018; Zhang et al., 2021).

Advantages associated with wireless stethoscopes

This overview found that wireless stethoscopes are more flexible in their use because wireless stethoscopes do not have dangling tubing, besides which wireless stethoscopes can amplify the auscultation of the sound produced so that they are more sensitive in their use (Hirosawa et al., 2021; Islam et al., 2019; Kalinauskienė et al., 2019). Another study stated that wireless stethoscopes have drawbacks, namely they are very sensitive to sound waves from very noisy environments, so they can affect the auscultation results (Gottlieb et al., 2018; Zhang et al., 2021).

Discussions

This literature review analyzed the findings of five articles featuring digital stethoscope testing that met inclusion criteria in various populations. Although the results of this review are not representative of the healthcare profession as a whole, they can provide an overview of digital stethoscope testing. We analyzed research papers on the sensitivity and specificity results of digital stethoscopes.

This systematic review found that wireless stethoscopes may have increased sensitivity concerning auscultation in the heart and lung compared with manual acoustic stethoscopes. This may be because digital stethoscopes can improve the quality of the sound produced during auscultation. Visualizing sonograms during auscultation may facilitate discrimination between different types of heart and lung sounds (Hirosawa et al., 2021b), and may improve sound quality (Tavel, 1996), which may contribute to improved auscultatory performance. Adjustments can also be made (Høyte et al., 2005).

Additionally, findings regarding wireless stethoscopes and manual acoustic stethoscopes show they have the same sensitivity. This is obtained because the development of manual acoustic stethoscopes that have tubing has often been carried out so that the auscultation results produced have high sensitivity. In addition, another study on a Bluetooth-based wireless stethoscope found that the measurement results were comparable to direct auscultation (Hirosawa et al., 2021), can eliminate external noise by using a bandpass filter and adaptive line enhancement techniques (Lakhe et al., 2016), use can be made using data transmission using Bluetooth with a distance of 3 meters 17 and a Bluetooth-based wireless stethoscope has the same function as an acoustic stethoscope (Sumartono, 2021).

More and more evidence shows that wireless stethoscopes have advantages over manual acoustic stethoscopes, including wireless stethoscopes that are considered more flexible in their use (Zhang et al., 2021). The wireless statoscope positively impacts healthcare providers, particularly nurses, while taking care of patients during pandemic sessions (Hidayat et al., 2021). A study showed that the development of a programmed wireless statoscope based on an efficient net would give accurate information to detect heartbeat sounds (Haq et al., 2021). In development of a wireless stethoscope with no modifications, the tube can be carried easily and flexibly because this device only consists of two parts, namely a modified diaphragm chest piece and for listening to it through a headset.

This device is suitable for use by nurses in critical areas because of its high mobility without disturbing the function of the stethoscope, namely to assist nurses in performing auscultation of the heart and lungs. In addition, several other studies on Bluetooth-based wireless stethoscopes explain that the design of wireless electronic stethoscopes eliminates the cable connecting conventional stethoscopes, which offers ease of use and mobility, makes them easy to carry everywhere, minimizes the spread of infection and facilitates auscultation training for health practitioners where it can be used simultaneously for evaluation (Mills et al., 2012).

Based on studies that found that wireless stethoscopes have a suggestion of increased sensitivity of auscultation heart and lungs compared with manual acoustic stethoscopes, the increased sensitivity makes wireless stethoscopes to be considered for use, particularly in critical patients with heart and lung problems (Hirosawa et al., 2021b; Islam et al., 2019; Kalinauskienė et al., 2019). Additionally, wireless stethoscopes can be used in auscultated obese patients, wherein they can hear a smaller sound, while wireless stethoscopes that use digital products can amplify the sound produced (Chowdhury et al., 2019).

The resulting sound enhancement is because the wireless stethoscope has a special feature, namely filter settings. Previous research explained that the filter setting can produce low and strong heart and lung signal frequencies and is quite sensitive (Jusak et al., 2020). With this, wireless stethoscopes have better auscultation results and can become assistive technologies from existing manual systems. In addition, a wireless-based stethoscope can reduce noise and improve listening to heart or lung sounds to minimize errors. Previous research has reported that a digital stethoscope with a condenser mic feature connected to a Pre-Amplifier can amplify voice signals up to 28.2 times; this can make a solution to the current stethoscope problem (Kurniawan, 2017).

The use of a wireless stethoscope still has problems, namely that it can be influenced by other signals around the environment so that it disrupts the sound transmission process. Besides that, a noisy environment can affect the quality of auscultation results, this is because wireless stethoscopes are very sensitive to sound waves from the surrounding environment. This wireless stethoscope problem should continue to be addressed to produce a higher quality stethoscope (McLane et al., 2021).

Conclusions

A wireless stethoscope to assist patients in a physical examination can be recommended for further research. The usefulness and ease of a wireless stethoscope in the practical patient assessment can be used by the patients and their families too. We agree that a wireless stethoscope for auscultation of the heart and lungs in critically ill patients can facilitate professional healthcare for the assessment of the patients without any obstacles.

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Conflict of Interest

There is no conflict of interest.

References

A-Mohannadi, A. *et al.* (2022) 'Conventional Clinical Methods for Predicting Heart Disease. Predicting Heart Failure: Invasive, Non-Invasive, Machine Learning and Artificial Intelligence Based Methods', (eds K.K. Sadasivuni, H.M. Ouakad, S. Al-Maadeed, H.C. Yalcin and I.B. Bahadur). 23–46. https://doi.org/10.1002/9781119813040.ch2

Andrès, E. *et al.* (2018) 'Respiratory sound analysis in the era of evidence-based medicine and the world of medicine 2.0.', *Journal of Medicine and Life*, 11(2), 89–106.

Barnett, C. F., O'Brien, C., & De Marco, T. (2022) 'Critical care management of the patient with pulmonary hypertension', *European Heart Journal. Acute Cardiovascular Care*, 11(1), 77–83. https://doi.org/10.1093/ehjacc/zuab113

Chowdhury, M. E. H. *et al.* (2019) 'Real-time smart-digital stethoscope system for heart diseases monitoring', *Sensors (Switzerland)*, 19(12). https://doi.org/10.3390/s19122781

Goldsworthy, S. *et al.* (2021) 'Do basic auscultation skills need to be resuscitated? A new strategy for improving competency among nursing students', *Nurse Education Today*, 97, 104722. https://doi.org/10.1016/j.nedt.2020.104722

Gottlieb, E. R., Aliotta, J. M., & Tammaro, D. (2018) 'Comparison of analogue and electronic stethoscopes for pulmonary auscultation by internal medicine residents', *Postgraduate Medical Journal*, 94(1118), 700–703. https://doi.org/10.1136/postgradmedj-2018-136052

Haq, H. F. D. U. *et al.* (2021) 'EfficientNet Optimization on Heartbeats Sound Classification', *2021 5th International Conference on Informatics and Computational Sciences (ICICoS)*, 216–221. https://doi.org/10.1109/ICICoS53627.2021.9651818

Harcharran, M. (2022) 'Assessment and examination of the cardiovascular system', *Practice Nursing*, 33(3), 98–104.

Hidayat, L. *et al.* (2021) 'EVALUASI PERSEPSI KEGUNAAN, DAN

KEMUDAHAN, WIRELESS STETHOSCOPE', JURNAL TEKNIK MESIN, 9(1), 143-148. Retrieved from https://ejournal3.undip.ac.id/index.php/jtm/article/view/35330

Hirosawa, T. *et al.* (2021a) 'The utility of real-time remote auscultation using a bluetooth-connected electronic stethoscope: Open-label randomized controlled pilot trial', *JMIR MHealth and UHealth*, 9(7), 1–11. https://doi.org/10.2196/23109

Hirosawa, T. *et al.* (2021b) 'The Utility of Real-Time Remote Auscultation Using a Bluetooth-Connected Electronic Stethoscope: Open-Label Randomized Controlled Pilot Trial', *JMIR MHealth and UHealth*, 9(7), e23109. https://doi.org/10.2196/23109

Høyte, H., Jensen, T., & Gjesdal, K. (2005a) 'Cardiac auscultation training of medical students: A comparison of electronic sensor-based and acoustic stethoscopes', *BMC Medical Education*, 5, 1–6. https://doi.org/10.1186/1472-6920-5-14

Høyte, H., Jensen, T., & Gjesdal, K. (2005b) 'Cardiac auscultation training of medical students: a comparison of electronic sensor-based and acoustic stethoscopes', *BMC Medical Education*, 5(1), 14. https://doi.org/10.1186/1472-6920-5-14

Hu, X. *et al.* (2017) 'Pulse oximetry and auscultation for congenital heart disease detection', *Pediatrics*, 140(4). https://doi.org/10.1542/peds.2017-1154

Islam, M. R. *et al.* (2019) 'A Wireless Electronic Stethoscope to Classify Children Heart Sound Abnormalities', *2019 22nd International Conference on Computer and Information Technology (ICCIT)*, 1–6. https://doi.org/10.1109/ICCIT48885.2019.9038406

Iversen, K. *et al.* (2006) 'Effect of teaching and type of stethoscope on cardiac auscultatory performance', *American Heart Journal*, 152(1), 85.e1-85.e7. https://doi.org/https://doi.org/10.1016/j.ahj.2006.04.013

Jusak, J., Puspasari, I., & Kusumawati, W. I. (2020) 'Pengolahan Sinyal Phonocardiography (PCG) Teori', Aplikasi dan Riset. Project Report. CV. Revka Prima Media, Surabaya. http://repository.dinamika.ac.id/id/eprint/5614

Kalinauskienė, E. *et al.* (2019) 'A comparison of electronic and traditional stethoscopes in the heart auscultation of obese patients', *Medicina (Lithuania)*, 55(4). https://doi.org/10.3390/medicina55040094

Kurniawan, D. (2017) 'Rancang Bangun Alat Deteksi Suara Paru-Paru Untuk Menganalisa Kelainan Paru-Paru Berbasis Android', *Elinvo (Electronics, Informatics, and Vocational Education)*, 2(2), 156–168. http://dx.doi.org/10.21831/elinvo.v2i2.17309

Lakhe, A. *et al.* (2016) 'Development of digital stethoscope for telemedicine.', *Journal of Medical Engineering & Technology*, 40(1), 20–24. https://doi.org/10.3109/03091902.2015.1116633

McLane, I. *et al.* (2021) 'Design and Comparative Performance of a Robust Lung Auscultation System for Noisy Clinical Settings', *IEEE Journal of Biomedical and Health Informatics*, 25(7), 2583–2594. https://doi.org/10.1109/JBHI.2021.3056916

Mehmood, M. *et al.* (2014) 'Comparing the auscultatory accuracy of health care professionals using three different brands of stethoscopes on a simulator', *Medical Devices (Auckland, N.Z.)*, 7, 273–281. https://doi.org/10.2147/MDER.S67784

Mills, G. A. *et al.* (2012) 'Wireless digital stethoscope using bluetooth technology', *International Journal of Engineering Science and Technology (IJEST)*, 4(08).

Page, M. J. *et al.* (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ, 372. https://doi.org/10.1136/BMJ.N71

Perri, A. G. (2010) 'High Quality Heart and Lung Auscultation System for Diagnostic Use on Remote Patients in Real Time', *The Open Biomedical Engineering Journal*, 4(1), 250–256. https://doi.org/10.2174/1874120701004010250

Popay, J. *et al.* (2006) 'Guidance on the conduct of narrative synthesis in systematic reviews', *A Product from the ESRC Methods Programme Version*, 1(1), b92.

Pratiwi, N. G. *et al.* (2021) 'A Review of Equipment and Signal Processing of The Automated Auscultation for Blood Pressure Measurement', *2021 3rd International Symposium on Material and Electrical Engineering Conference (ISMEE)*, 26–31. https://doi.org/10.1109/ISMEE54273.2021.9774036

Qu, M. *et al.* (2021) 'Monitoring of physiological sounds with wearable device based on piezoelectric MEMS acoustic sensor', *Journal Of Micromechanics and Microengineering*, 32(1), 14001. DOI: 10.1088/1361-6439/ac371e

Saketkoo, L. A. *et al.* (2021) 'Health-related quality of life (Hrqol) in sarcoidosis: diagnosis, management, and health outcomes', *Diagnostics*, 11(6), 1089. https://doi.org/10.3390/diagnostics11061089

Sarkar, M. *et al.* (2015) 'Auscultation of the respiratory system', *Annals of Thoracic Medicine*, 10(3), 158–168. https://doi.org/10.4103/1817-1737.160831

Sumartono, A. A. (2021) 'Stetoskop bluetooth menggunakan sensor max 9814 berbasis esp 32'

Swarup, S., & Makaryus, A. N. (2018) 'Digital stethoscope: technology update', *Medical Devices (Auckland, N.Z.)*, 11, 29–36. https://doi.org/10.2147/MDER.S135882

Tavel, M. E. (1996) 'Cardiac auscultation', *A glorious past--but does it have a future? Circulation*, 93(6), 1250–1253. https://doi.org/10.1161/01.cir.93.6.1250

Tian, S. *et al.* (2019) 'Smart healthcare: making medical care more intelligent', *Global Health Journal*, 3(3), 62–65. https://doi.org/10.1016/j.glohj.2019.07.001

Zhang, P. *et al.* (2021) 'Lung auscultation of hospitalized patients with SARSCoV- 2 pneumonia via a wireless stethoscope', *International Journal of Medical Sciences*, 18(6), 1415–1422. https://doi.org/10.7150/ijms.54987.

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