Review

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Review

The Evolution of Auscultation: Harnessing Artificial Intelligence (AI) for the Future of Bedside Diagnostics

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Abstract

Background: Auscultation remains a fundamental component of physical examination - providing physicians with important information about many body systems; including gastrointestinal and cardiovascular health. Since its formalization in the 19th century by René Laennec with the invention of the stethoscope, auscultation has changed significantly. **Methods:** This review explores the historical development of auscultation from mediate to immediate methods, and highlights the technological advancements - including artificial intelligence (AI)-integrated stethoscopes and their clinical uses in primary care, pediatrics, cardiology, and respiratory medicine. It also looks at the limitations of implementing such technologies in modern day clinical practice. **Results:** Digital stethoscopes have improved sound amplification and diagnostic accuracy; while AI technologies have become a powerful adjunct in recent years, allowing for automated analysis of body sounds, reducing inter-observer variability, and expanding access to diagnostics through telemedicine. However, challenges remain; including data limitations, ethical considerations, and clinical acceptance. **Conclusions:** Auscultation is set to play a key role in personalized and predictive medicine as wearable and remote AI-driven diagnostic technologies continue to advance - bridging the gap between cutting-edge innovation and conventional bedside expertise. One such initiative, the TAPEX framework, emphasizes the integration of digital tools - such as AI-assisted auscultation - into physical examination, to enhance diagnostic precision and clinical confidence. (1,2)

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1. Introduction

Auscultation, derived from the Latin term *auscultare*, meaning "to listen," is a fundamental clinical skill in medical diagnostics. It involves listening to internal body sounds, such as the heart, lungs, and abdomen, typically using a stethoscope. This non-invasive technique remains a crucial part of physical examinations, allowing healthcare professionals to detect abnormalities in cardiac, pulmonary, and gastrointestinal function. (3,4)

Historically, immediate auscultation—placing the ear directly onto the patient's body—was the primary method used for diagnosing internal conditions. While this technique provided valuable clinical insights, it had limitations, including hygiene concerns, lack of sound amplification, and reliance on a physician's auditory perception. In 1816, René Laennec revolutionized auscultation with the invention of the stethoscope, enabling physicians to assess internal sounds with greater accuracy

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and patient comfort. Over time, the stethoscope evolved into a sophisticated diagnostic tool, incorporating digital enhancements to improve sound clarity and analysis. (5–7)

More recently, the integration of artificial intelligence (AI) into auscultation has further transformed diagnostic capabilities. AI-assisted auscultation enables automated recognition of cardiac murmurs, lung abnormalities, and bowel sounds, reducing diagnostic variability among physicians. With advancements in machine learning and digital stethoscopes, auscultation continues to play a pivotal role in modern medicine, bridging traditional clinical examination methods with cutting-edge technology. Amidst this accelerating shift towards digital health and remote diagnostics, AI-enhanced auscultation offers a timely solution for improving clinical decision-making in both tradition and telemedicine settings. This article explores the evolution of auscultation, tracing its journey from manual techniques to AI-driven diagnostics, and examines its impact on healthcare practices. (1,6,9)

2. The Origins of Auscultation

Early Manual Techniques

Auscultation, the practice of listening to internal body sounds for diagnostic purposes, dates back to ancient civilizations. Early physicians relied on immediate auscultation, where they placed their ears directly on the patient's body to detect abnormalities. This method was widely used by Hippocrates, who instructed his students to listen to the chest for signs of respiratory diseases. Similarly, historical texts such as the Ebers Papyrus (circa 1500 BCE) and Hindu Vedas (1200 BCE) reference the importance of auditory assessment in diagnosing illnesses. (10–13)

While immediate auscultation provided valuable diagnostic insights, it had several limitations. The technique was highly subjective, as accuracy depended on the physician’s hearing ability and interpretation skills. Additionally, it posed challenges in terms of patient modesty and hygiene. These issues underscored the need for a more refined and effective auscultation method. (14,15)

The Invention of the Stethoscope

A breakthrough in auscultation came in 1816 when French physician René-Théophile-Hyacinthe Laennec revolutionized the practice by inventing the stethoscope. The idea reportedly stemmed from an observation in which he noticed how sound travelled efficiently through solid objects. Laennec rolled up a sheet of paper into a cylinder and placed one end on the patient’s chest while listening from the other. He found that this method amplified heart sounds more clearly than direct ear-to-chest contact. (16–18)

Laennec subsequently designed a wooden, monaural stethoscope approximately 25 cm long, which he named after the Greek words *stethos* (chest) and *skopein* (to examine). His landmark publication, *De l’Auscultation Médiate* (1819), detailed his findings and techniques, solidifying the stethoscope as an essential diagnostic tool in medicine. The device enabled physicians to diagnose conditions such as pneumonia, tuberculosis, and heart murmurs with greater accuracy. (19–21)

Over the years, the stethoscope underwent several modifications, evolving into the modern binaural stethoscope used today. The widespread adoption of this instrument revolutionized medical practice by standardizing auscultation and improving diagnostic precision.

3. The Advancements in Auscultation Technology

Transition to Digital Stethoscopes

The late 20th century marked a significant shift in auscultation technology with the emergence of digital stethoscopes. Unlike traditional acoustic models, digital stethoscopes amplify body sounds through electronic sensors and convert them into digital signals for enhanced auditory perception.

This technological advancement addressed several limitations of acoustic stethoscopes, particularly in environments with high ambient noise or for users with hearing impairments. (4,22,23)

One of the major advantages of digital stethoscopes is their ability to reduce background noise, thus improving diagnostic accuracy. This is achieved through electronic noise filtration and amplification, allowing physicians to isolate specific frequencies within heart or lung sounds. Another notable feature is the capability for sound recording and data storage.

Clinicians can save auscultation sounds for later review, comparison, and even remote diagnosis, facilitating telemedicine and artificial intelligence-assisted diagnostics. (24–26)

When comparing acoustic and digital stethoscopes, traditional models rely solely on the physician's auditory skills and are susceptible to environmental interference. In contrast, digital stethoscopes provide amplified, high-fidelity sound, improving the detection of subtle murmurs and adventitious lung sounds. However, digital models require a power source and are generally more expensive, which may limit their adoption in resource-constrained settings. A comparison of the key features of tradition, digital, and AI-assisted auscultation devices is summarized in Table 1. (27,28)

Table 1. Comparative Features of Traditional, Digital, and AI-Assisted Auscultation.

Feature	**Traditional Stethoscope**	**Digital Stethoscope**	**AI-Assisted Auscultation**
Sound Amplification	Passive, depends on clinician's hearing	Electronic amplification	Enhanced through digital processing and filtering
Background Noise Filtering	None	Basic noise reduction (depending on model)	Advanced filtering algorithms using machine learning (24, 26, 35)
Diagnostic Support	Relies solely on clinician's interpretation	Enhanced audio but no automated interpretation	Provides real-time diagnostic suggestions using trained AI models (7, 36, 37)
Data Recording and Sharing	Not Possible	Enables sound recording and cloud storage	Allows remote diagnosis, telemedicine integration (8, 23, 40)
Learning Curve	Low	Moderate	Requires clinician training and digital literacy (56-58)

Accessibility in Remote Settings	Limited	Moderate	High; suitable for community, rural, and low-resource settings (41, 51)
Cost	Low	Moderate to High	Higher initial cost; but scalable with wider adoption

Challenges in Traditional Auscultation

Despite being a cornerstone of clinical practice, traditional auscultation presents several challenges. One of the most significant limitations is its subjectivity, as it relies entirely on the clinician's experience and auditory sensitivity. Studies have shown considerable variability in auscultation findings among healthcare providers, particularly in distinguishing different types of lung sounds (3,24,29)

Additionally, there is a lack of standardization in auscultation-based diagnostics. Different clinicians may interpret the same sound differently, leading to potential misdiagnosis or oversight of critical conditions. This variability has been a driving factor behind the development of AI-assisted auscultation, which aims to introduce greater objectivity into diagnostic assessments. (4,23,30,31)

Moreover, external noise interference can further compromise auscultation accuracy. Traditional stethoscopes do not have the capability to filter out extraneous sounds, making it challenging to detect subtle abnormalities in noisy environments such as emergency rooms or ambulances. These challenges underscore the importance of advancing auscultation technology, ensuring greater accuracy, reliability, and accessibility for healthcare professionals. (32,33)

4. The Integration of AI in Auscultation

How AI-Driven Auscultation Works

The integration of artificial intelligence (AI) into auscultation has revolutionized the diagnostic process by enhancing the accuracy and efficiency of interpreting bodily sounds. This advancement begins with the collection of high-fidelity digital sound data using electronic stethoscopes, which capture detailed acoustic information from the heart and lungs. These digital recordings are then processed through AI-based algorithms designed to filter out ambient noise and enhance the clarity of the relevant sounds, ensuring that the data analyzed is of the highest quality. (34,35)

Subsequently, machine learning models analyze these refined sounds to identify patterns indicative of pathological conditions. These models are trained on extensive datasets comprising both normal and abnormal sound profiles, enabling them to detect anomalies with a high degree of accuracy. For instance, a study demonstrated that AI-assisted auscultation could accurately detect heart valve failure up to 90% of the time, surpassing traditional methods. The final step involves generating automated diagnostic outputs that provide real- time decision support to physicians, facilitating prompt and accurate clinical assessments. (36,37)

Advantages of AI-Assisted Auscultation

The incorporation of AI into auscultation practices offers several significant benefits:

- **Increased Diagnostic Accuracy and Early Disease Detection**: AI algorithms enhance the precision of detecting subtle abnormalities in heart and lung sounds, leading to earlier and

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more reliable diagnoses. This improvement is crucial for conditions where early intervention can significantly impact patient outcomes. (36)

- **Standardization and Reduction of Inter-Clinician Variability**: Traditional auscultation is subject to variability based on the clinician's experience and auditory acuity. AI-driven tools provide consistent analyses, reducing subjective discrepancies and ensuring uniformity in diagnostic conclusions across different healthcare providers. (38,39)
- **Improved Accessibility and Utility in Remote Healthcare Settings**: AI-assisted auscultation devices can be integrated into telemedicine platforms, enabling remote monitoring and diagnosis. This capability is particularly beneficial in underserved or rural areas, where access to specialized medical care is limited. For example, AI- powered digital auscultation has been effectively utilized in community pharmacies to detect heart valve diseases, expanding the reach of quality healthcare services (40,41)
- **Real-Time Monitoring and Integration with Telemedicine**: The ability of AI- enabled stethoscopes to provide continuous, real-time monitoring of patients' cardiac and respiratory status allows for timely medical interventions. This feature is especially advantageous in managing chronic conditions and in settings where immediate medical response is critical. (1,40,42)

5. Clinical Applications of AI-Driven Auscultation

Cardiology

In the field of cardiology, artificial intelligence (AI) has significantly enhanced the detection and diagnosis of various cardiac conditions. AI algorithms are capable of identifying heart murmurs, arrhythmias, and valvular diseases with high precision. For instance, AI-assisted auscultation has demonstrated proficiency in distinguishing between innocent and pathological heart murmurs, thereby aiding in early diagnosis and reducing unnecessary referrals. Moreover, AI systems can predict heart failure and other cardiac abnormalities by analyzing subtle changes in heart sounds, enabling timely interventions and improved patient outcomes.(43–45)

Pulmonology

AI-driven auscultation has also made strides in pulmonology by enhancing the analysis of lung sounds to detect respiratory conditions. Advanced AI algorithms can accurately identify patterns associated with pneumonia, asthma, and chronic obstructive pulmonary disease (COPD). A study evaluating an AI algorithm for detecting breath sounds in children with pulmonary diseases found that the AI system outperformed general pediatricians in dentifying adventitious breath sounds, such as crackles and wheezes, which are indicative of various respiratory conditions. Additionally, AI-assisted auscultation plays a crucial role in tuberculosis screening by recognizing specific acoustic signatures associated with the disease, facilitating early diagnosis and treatment. (46–48)

Pediatrics

Pediatric auscultation presents unique challenges due to patient variability and the subtlety of pathological sounds in children. AI-assisted diagnostic tools have been developed to improve accuracy in neonatal and pediatric care. For example, AI-enhanced stethoscopes have been utilized in telemedicine to assess heart murmurs remotely, reducing unnecessary hospital visits and providing timely evaluations. Furthermore, AI algorithms have been employed to analyze neonatal heart and lung sounds, ensuring high-quality assessments in telehealth applications. (49,50)

Primary Care and Telemedicine

In primary care settings, AI-driven auscultation has become an invaluable tool during routine physical examinations. The integration of AI enhances the clinician's ability to detect abnormalities that might be missed during traditional auscultation. Moreover, the rise of telemedicine has amplified the importance of AI-assisted auscultation in remote patient monitoring and home-based healthcare. Devices equipped with AI capabilities allow for real- time analysis of heart and lung sounds, facilitating accurate remote assessments and continuous monitoring. This advancement is particularly beneficial in managing chronic diseases and providing care to patients in underserved areas. (51,52)

6. Challenges and Limitations

Data Availability and Algorithm Training

The development of robust AI-driven auscultation systems necessitates access to large, high-quality datasets for effective machine learning model training. However, acquiring such comprehensive datasets is challenging due to factors like patient privacy concerns and the variability in data collection methods. A study exploring AI heart murmur detection highlighted that limited data diversity can introduce biases into AI models, potentially affecting their generalizability across different populations. This underscores the need for diverse and representative data to ensure AI systems perform accurately across varied demographic groups. (53–55)

Clinical Acceptance and Physician Training

Integrating AI-driven diagnostics into traditional clinical practice faces resistance from healthcare professionals accustomed to conventional methods. This reluctance often stems from a lack of familiarity with AI technologies and concerns about their reliability. A qualitative interview study with healthcare leaders in Sweden revealed that successful implementation of AI in healthcare requires comprehensive training programs to enhance clinicians' understanding and confidence in AI-integrated auscultation tools. Such educationalinitiatives are crucial for fostering acceptance and effective utilization of AI technologies in clinical settings. (56–60)

Ethical and Legal Concerns

The deployment of AI-based diagnostics raises significant ethical and legal issues, particularly regarding patient data privacy and security. AI systems rely on extensive patient data, which necessitates stringent measures to protect sensitive information from breaches and unauthorized use. Additionally, regulatory challenges persist in implementing AI in clinical environments. The U.S. Food and Drug Administration (FDA) has recognized the need for a tailored regulatory framework to address the unique considerations posed by AI technologies in healthcare. Ensuring compliance with evolving regulations and maintaining patient trust is paramount as AI continues to integrate into medical practice. Another barrier to adoption lies in the 'black box' nature of many AI systems, where the rationale behind diagnostic decisions may not be transparent. This lack of explainability can affect clinicians trust and acceptance, underscoring the need for interpretable AI models. (61–64)

7. Future Perspectives

Advancements in Wearable and Portable AI Auscultation Devices

The integration of artificial intelligence (AI) into wearable health monitoring devices is poised to revolutionize continuous patient care. AI-powered stethoscopes, such as the Mintti Smartho-D2, exemplify this innovation by enabling real-time cardiac monitoring in home settings. These devices analyze heart sounds to provide immediate insights into cardiovascular health, facilitating early detection of conditions like arrhythmias and murmurs. The portability and user-friendly design of

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such devices make them particularly advantageous for home-based and ambulatory care, offering continuous monitoring without the need for frequent clinical visits. (38,48)

Development of Fully Automated Diagnostic Systems

AI's role in healthcare is expanding beyond monitoring to include predictive diagnostics. Researchers at Penn State University have developed AI models capable of predicting the progression of autoimmune diseases by analyzing complex datasets, thereby enabling early interventions and personalized treatment plans (Penn State University, 2024). Additionally, the fusion of AI with wearable sensors facilitates real-time health monitoring and rapid diagnostics, enhancing patient outcomes and healthcare efficiency. These advancements suggest a future where fully automated diagnostic systems can analyze auscultation data to forecast disease trajectories, improving clinical decision-making. (1,64,65)

Potential for Personalized Medicine

1. The application of AI in auscultation is also paving the way for personalized medicine. By integrating AI-driven analysis with wearable devices, healthcare providers can continuously monitor individual health metrics, allowing for tailored interventions. For instance, AI-enhanced wearable sensors can detect early signs of chronic conditions, enabling proactive and personalized healthcare strategies. This approach aligns with the principles of precision medicine, where treatments and preventive strategies are customized based on individual patient data. (66–68)

8. Conclusions

The practice of auscultation has undergone a remarkable transformation since its inception in the early 19th century. In 1816, French physician René Laënnec introduced the first stethoscope, a simple hollow tube that revolutionized the way physicians examined internal sounds, marking the birth of mediate auscultation. This innovation laid the foundation for modern diagnostic techniques, evolving from rudimentary tools to sophisticated devices.

In recent years, the integration of artificial intelligence (AI) into auscultation has significantly impacted medical practice. AI-enhanced diagnostic tools, such as digital stethoscopes equipped with machine learning algorithms, have improved the accuracy of detecting cardiac anomalies and respiratory conditions. These advancements facilitate early diagnosis and intervention, thereby enhancing patient outcomes.

Despite these technological strides, the role of human expertise remains indispensable. The synergy between clinician judgment and AI support ensures a comprehensive approach to patient care. While AI provides data-driven insights, physicians apply contextual understanding and experience, leading to more nuanced and personalized diagnoses.

Looking ahead, auscultation is poised to further evolve within an increasingly technology-driven healthcare system. The development of AI-powered wearable devices promises continuous monitoring capabilities, enabling real-time health assessments and proactive management of diseases. As these technologies become more integrated into clinical practice, they hold the potential to transform traditional diagnostic paradigms, making healthcare more predictive and personalized. Ongoing research, alongside education and training of healthcare providers, will be essential to fully realize the potential of AI-augmented auscultation in mainstream clinical practice.

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References

1 Chowdhury MEH, Khandakar A, Alzoubi K, Mansoor S, M. Tahir A, Reaz MBI, et al. Real-Time Smart-Digital Stethoscope System for Heart Diseases Monitoring. Sensors (Basel). 2019 Jun 20;19(12):2781.

2 Hanif, M. I., Hegazi, J., Sarrafan, S., Mohamed, M., Elashmawy, S., & Iftikhar, I. (2025). TAPEX (Technology Assisted Physical Examinoscope): Advancing physical examination through technology for objective assessment. Manuscript submitted for publication at Journal of Medical Education and Curricular Development.

3 Arts L, Lim EHT, van de Ven PM, Heunks L, Tuinman PR. The diagnostic accuracy of lung auscultation in adult patients with acute pulmonary pathologies: a meta-analysis. Sci Rep. 2020 Apr 30;10(1):7347.

4 Davidsen AH, Andersen S, Halvorsen PA, Schirmer H, Reierth E, Melbye H. Diagnostic accuracy of heart auscultation for detecting valve disease: a systematic review. BMJ Open. 2023 Mar 1;13(3):e068121.

5 Kim Y, Hyon Y, Lee S, Woo SD, Ha T, Chung C. The coming era of a new auscultation system for analyzing respiratory sounds. BMC Pulm Med. 2022 Mar 31;22:119.

6 Hanna IR, Silverman ME. A history of cardiac auscultation and some of its contributors. American Journal of Cardiology. 2002 Aug 1;90(3):259–67.

7 1816-1882: Early Stethoscope – EMS Museum [Internet]. [cited 2025 Feb 22]. Available from: https://emsmuseum.org/collections/archives/stethoscopes/stethoscopes

8 Lv J, Dong B, Lei H, Shi G, Wang H, Zhu F, et al. Artificial intelligence-assisted auscultation in detecting congenital heart disease. Eur Heart J Digit Health. 2021 Jan 6;2(1):119–24.

9 Jani V, Danford DA, Thompson WR, Schuster A, Manlhiot C, Kutty S. The discerning ear: cardiac auscultation in the era of artificial intelligence and telemedicine. European Heart Journal - Digital Health. 2021 Sep 1;2(3):456–66.

10 Montinari MR, Minelli S. The first 200 years of cardiac auscultation and future perspectives. J Multidiscip Healthc. 2019 Mar 6;12:183–9.

11 Vincent R. I Look Into the Chest: History and Evolution of Stethoscope. Journal of the Practice of Cardiovascular Sciences. 2022 Dec;8(3):168.

12 Auscultatory Interregnum | Circulation [Internet]. [cited 2025 Feb 22]. Available from: https://www.ahajournals.org/doi/10.1161/CIRCULATIONAHA.120.046430

13 Tully PA, Kwa L, Buckley A, Hu R, Chen S, Long D, et al. Lung auscultation versus point-of-care ultrasound for assessment of basal lung excursion at maximal inspiration: An exploratory study. Anaesth Intensive Care. 2022 May 1;50(3):255–7.

14 Choudry M, Stead TS, Mangal RK, Ganti L. The History and Evolution of the Stethoscope. Cureus. 14(8):e28171.

15 Harbison J. "The old guessing tube": 200 years of the stethoscope. QJM. 2017 Jan;110(1):9–10.

16 Kligfield P. Laennec and the discovery of mediate auscultation. Am J Med. 1981 Feb;70(2):275–8.

17 Tomos I, Karakatsani A, Manali ED, Papiris SA. Celebrating Two Centuries since the Invention of the

Stethoscope. René Théophile Hyacinthe Laënnec (1781-1826). Ann Am Thorac Soc. 2016 Oct;13(10):1667–70.

18 The Centennial of the Stethoscope | JAMA | JAMA Network [Internet]. [cited 2025 Feb 22]. Available from: https://jamanetwork.com/journals/jama/article-abstract/2530518

19 Fayssoil A. René Laennec (1781-1826) and the invention of the stethoscope. Am J Cardiol. 2009 Sep 1;104(5):743–4.

20 Roguin A. Rene Theophile Hyacinthe Laënnec (1781–1826): The Man Behind the Stethoscope. Clin Med Res. 2006 Sep;4(3):230–5.

21 2020 ACC/AHA Guideline for the Management of Patients With Valvular Heart Disease: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines | Circulation [Internet]. [cited 2025 Feb 22]. Available from: https://www.ahajournals.org/doi/10.1161/CIR.0000000000000923

22 Lakhe A, Sodhi I, Warrier J, Sinha V. Development of digital stethoscope for telemedicine. Journal of Medical Engineering & Technology. 2016 Jan 2;40(1):20–4.

23 Pereira D, Castro A, Gomes P, Areias JCNC, Reis ZSN, Coimbra MT, et al. Digital Auscultation: Challenges and Perspectives. In: Encyclopedia of E-Health and Telemedicine [Internet]. IGI Global Scientific Publishing; 2016 [cited 2025 Feb 10]. p. 910–27. Available from: https://www.igi-global.com/chapter/digital-auscultation/www.igi- global.com/chapter/digital-auscultation/152013

24 Koning C, Lock A. A systematic review and utilization study of digital stethoscopes for cardiopulmonary assessments. Journal of Medical Research and Innovation. 2021 Dec 31;5(2):4–14.

25 Bai YW, Lu CL. The embedded digital stethoscope uses the adaptive noise cancellation filter and the type I Chebyshev IIR bandpass filter to reduce the noise of the heart sound. In: Proceedings of 7th International Workshop on Enterprise networking and Computing in Healthcare Industry, 2005 HEALTHCOM 2005 [Internet]. 2005 [cited 2025 Feb 22]. p. 278–81. Available from: https://ieeexplore.ieee.org/abstract/document/1500459

26 Lee K, Ji Y, Jeon Y, Park YC. Development and Implementation of Noise-Canceling Technology for Digital Stethoscope. Journal of Biomedical Engineering Research. 2013;34(4):204–11.

27 Leng S, Tan RS, Chai KTC, Wang C, Ghista D, Zhong L. The electronic stethoscope. BioMed Eng OnLine. 2015 Jul 10;14(1):66.

28 Nuttall C, Teng CC. Design and Implementation of a Low Cost, Open Access Digital Stethoscope for Social Distanced Medical Care and Tele Auscultation: Stethogram. In: Proceedings of the 5th International Conference on Medical and Health Informatics [Internet]. New York, NY, USA: Association for Computing Machinery; 2021 [cited 2025 Feb 21]. p. 129–33. (ICMHI '21). Available from: https://doi.org/10.1145/3472813.3473178

29 Wang Z, Sun Z. Performance evaluation of lung sounds classification using deep learning under variable parameters. EURASIP Journal on Advances in Signal Processing. 2024 Apr 15;2024(1):51.

30 Gurung A, Scrafford CG, Tielsch JM, Levine OS, Checkley W. Computerized Lung Sound Analysis as diagnostic aid for the detection of abnormal lung sounds: a systematic review and meta-analysis. Respir Med. 2011 Sep;105(9):1396–403.

31 Kala A, McCollum ED, Elhilali M. Reference free auscultation quality metric and its trends. Biomedical Signal Processing and Control. 2023 Aug 1;85:104852.

32 Iskandar AS, Prihatmanto AS, Rangkuti S. Design of electronic stethoscope to prevent error analysis of heart patients circumstances. In: 2014 IEEE 4th International Conference on System Engineering and Technology (ICSET) [Internet]. 2014 [cited 2025 Feb 22]. p. 1–4. Available from:

https://ieeexplore.ieee.org/document/7111789
33 Rennoll V, McLane I, Emmanouilidou D, West J, Elhilali M. Electronic Stethoscope Filtering Mimics the Perceived Sound Characteristics of Acoustic Stethoscope. IEEE J Biomed Health Inform. 2021 May;25(5):1542–9.
34 CoLab [Internet]. [cited 2025 Feb 22]. An electronic stethoscope for heart diseases based on micro-electro-mechanical-system microphone. Available from: https://colab.ws/articles/10.1109%2FINDIN.2016.7819285
35 Rusydi MI, Ningsih EM, Pawawoi A, Nofendra R, Windasari N. Design a Stethoscope Digital to Keep the Medical Practitioner at an Adequate Distance While Examining the Patient. IOP Conf Ser: Mater Sci Eng. 2021 Jan;1041(1):012015.
36 Graham C. Computer-assisted auscultation proves effective at detecting early-stage heart disease [Internet]. Johns Hopkins Malone Center for Engineering in Healthcare. 2021 [cited 2025 Feb 22]. Available from: https://malonecenter.jhu.edu/computer-assisted- auscultation-proves-effective-at-detecting-early-stage-heart-disease/
37 Jani V, Danford DA, Thompson WR, Schuster A, Manlhiot C, Kutty S. The discerning ear: cardiac auscultation in the era of artificial intelligence and telemedicine. Eur Heart J Digit Health. 2021 Sep;2(3):456–66.
38 Kim Y, Hyon Y, Woo SD, Lee S, Lee SI, Ha T, et al. Evolution of the Stethoscope: Advances with the Adoption of Machine Learning and Development of Wearable Devices. Tuberc Respir Dis (Seoul). 2023 Oct;86(4):251–63.
39 Drie MV, Harris A. The stethoscope goes digital: Learning through attention, distraction and distortion. Gesnerus. 2020 Nov 6;77(1):123–48.
40 Baraeinejad B, Shams M, Hamedani MS, Nasiri-Valikboni A, Forouzesh M, Fakhraeelotfabadi S, et al. Clinical IoT in Practice: A Novel Design and Implementation of a Multi-functional Digital Stethoscope for Remote Health Monitoring. [cited 2025 Feb 22]; Available from: https://www.authorea.com/doi/full/10.36227/techrxiv.24459988?commit=b43b9f4d1afe8c05b f9c1ae8b246254a50f46831
41 Park DE, Watson NL, Focht C, Feikin D, Hammitt LL, Brooks WA, et al. Digitally recorded and remotely classified lung auscultation compared with conventional stethoscope classifications among children aged 1-59 months enrolled in the Pneumonia Etiology Research for Child Health (PERCH) case-control study. BMJ Open Respir Res. 2022 May;9(1):e001144.
42 Foche-Perez I, Ramirez-Payba R, Hirigoyen-Emparanza G, Balducci-Gonzalez F, Simo-Reigadas FJ, Seoane-Pascual J, et al. An open real-time tele-stethoscopy system. BioMed Eng OnLine. 2012 Aug 23;11(1):57.
43 Ghanayim T, Lupu L, Naveh S, Bachner-Hinenzon N, Adler D, Adawi S, et al. Artificial Intelligence-Based Stethoscope for the Diagnosis of Aortic Stenosis. The American Journal of Medicine. 2022 Sep 1;135(9):1124–33.
44 Omarov B, Saparkhojayev N, Shekerbekova S, Akhmetova O, Sakypbekova M, Kamalova G, et al. Artificial Intelligence in Medicine: Real Time Electronic Stethoscope for Heart Diseases Detection. CMC. 2021;70(2):2815–33.
45 Ogawa S, Namino F, Mori T, Sato G, Yamakawa T, Saito S. AI diagnosis of heart sounds differentiated with super StethoScope. Journal of Cardiology. 2024 Apr 1;83(4):265– 71.
46 Sethi AK, Muddaloor P, Anvekar P, Agarwal J, Mohan A, Singh M, et al. Digital Pulmonology Practice with Phonopulmography Leveraging Artificial Intelligence: Future Perspectives Using Dual Microwave Acoustic Sensing and Imaging. Sensors. 2023 Jan;23(12):5514.
47 Zhu H, Lai J, Liu B, Wen Z, Xiong Y, Li H, et al. Automatic pulmonary auscultation grading diagnosis of

Coronavirus Disease 2019 in China with artificial intelligence algorithms: A cohort study. Computer Methods and Programs in Biomedicine. 2022 Jan 1;213:106500.

48 Lee KR, Kim T, Im S, Lee YJ, Jeong S, Shin H, et al. A Wearable Stethoscope for Accurate Real-Time Lung Sound Monitoring and Automatic Wheezing Detection Based on an AI Algorithm. Engineering [Internet]. 2025 Jan 17 [cited 2025 Feb 22]; Available from: https://www.sciencedirect.com/science/article/pii/S2095809925000086

49 Ijaz MT, Ijaz N. Beyond stethoscopes: Advancing Diagnostic Precision in Pediatric Cardiology. Revista Ecuatoriana de Pediatría. 2024 Aug 26;25(2):46–53.

50 Emeryk A, Derom E, Janeczek K, Kuźnar-Kamińska B, Zelent A, Łukaszyk M, et al. Home Monitoring of Asthma Exacerbations in Children and Adults With Use of an AI-Aided Stethoscope. The Annals of Family Medicine. 2023 Nov 1;21(6):517–25.

51 Dhillon HS, Doermann AC, Walcoff P. Telemedicine and rural primary health care: An analysis of the impact of telecommunications technology. Socio-Economic Planning Sciences. 1978 Jan 1;12(1):37–48.

52 Bratton RL, Cody C. Telemedicine Applications in Primary Care: A Geriatric Patient Pilot Project. Mayo Clinic Proceedings. 2000 Apr 1;75(4):365–8.

53 Zhang L, Cheng Z, Xu D, Wang Z, Cai S, Hu N, et al. Developing an AI-assisted digital auscultation tool for automatic assessment of the severity of mitral regurgitation: protocol for a cross-sectional, non-interventional study. BMJ Open. 2024 Mar 1;14(3):e074288.

54 Krones F, Walker B. From theoretical models to practical deployment: A perspective and case study of opportunities and challenges in AI-driven cardiac auscultation research for low-income settings. PLOS Digital Health. 2024 Dec 4;3(12):e0000437.

55 ZCHSound: Open-Source ZJU Paediatric Heart Sound Database With Congenital Heart Disease | IEEE Journals & Magazine | IEEE Xplore [Internet]. [cited 2025 Feb 22]. Available from: https://ieeexplore.ieee.org/abstract/document/10384868

56 Hou K, Xia S, Bejerano E, Wu J, Jiang X. ARSteth: Enabling Home Self-Screening with AR-Assisted Intelligent Stethoscopes. In: Proceedings of the 22nd International Conference on Information Processing in Sensor Networks [Internet]. New York, NY, USA: Association for Computing Machinery; 2023 [cited 2025 Feb 21]. p. 205–18. (IPSN '23). Available from: https://dl.acm.org/doi/10.1145/3583120.3586962

57 Pyles L, Hemmati P, Pan J, Yu X, Liu K, Wang J, et al. Initial Field Test of a Cloud- Based Cardiac Auscultation System to Determine Murmur Etiology in Rural China. Pediatr Cardiol. 2017 Apr 1;38(4):656–62.

58 Toward a Smart Stethoscope: Correlation Between Trachea Internal Air Pathway Geometry and the Auscultation Signal Response - ProQuest [Internet]. [cited 2025 Feb 22]. Available from: https://www.proquest.com/openview/5352a8a69902425ff8037ffb2a46cf4f/1?pq-origsite=gscholar&cbl=18750

59 Soroush L, Hafeez-Baig A, Gururajan R. Clinicians' Perception of Using Digital Stethoscopes in Telehealth Platform: Queensland Telehealth Preliminary Study. ACIS 2010 Proceedings [Internet]. 2010 Jan 1; Available from: https://aisel.aisnet.org/acis2010/43

60 Gururajan R, Tsai HS, Chen H. Using digital stethoscopes in remote patient assessment via wireless networks: the user's perspective. International Journal of Advanced Networking and Applications. 2011 Jan 1;3(3):1140–6.

61 Cohen IG. Digital Health Care Outside of Traditional Clinical Settings: Ethical, Legal, and Regulatory Challenges and Opportunities. Cambridge University Press; 2024. 230 p.

62 Lupton M. Some ethical and legal consequences of the application of artificial intelligence in the field of

medicine. Trends Med [Internet]. 2018 [cited 2025 Feb 22];18(4). Available from: https://www.oatext.com/some-ethical-and-legal-consequences-of-the- application-of-artificial-intelligence-in-the-field-of-medicine.php

63 Automated differential diagnostics of respiratory diseases using an electronic stethoscope - ProQuest [Internet]. [cited 2025 Feb 22]. Available from: https://www.proquest.com/openview/debe57bd3fc2bcb57e831dbbf6315974/1?pq-origsite=gscholar&cbl=2026628

64 Kostick-Quenet K, Estep J, Blumenthal-Barby JS. Ethical Concerns for Remote Computer Perception in Cardiology: New Stages for Digital Health Technologies, Artificial Intelligence, and Machine Learning. Circulation: Cardiovascular Quality and Outcomes. 2024 May;17(5):e010717.

65 Joarder T, Tune SNBK, Islam AA, Islam A, Roy AD, McCollum ED, et al. End-user acceptability of a prototype digital stethoscope to diagnose childhood pneumonia- a qualitative exploration from Sylhet, Bangladesh. BMC Digital Health. 2023 Jul 13;1(1):26.

66 AIDiagnosticDigital Cardiac AuscultationPatient-CenteredCare [Internet]. Minttihealth. 2024 [cited 2025 Feb 22]. Available from: https://minttihealth.com/ai-assisted- diagnostic-tools-and-digital-cardiac-auscultation-enhancing-patient-centered-care-in-the-age- of-ai-for-improved-outcomes/

67 Tomasevic S, Blagojevic A, Geroski T, Jovicic G, Milicevic B, Prodanovic M, et al. AI-Driven Decision Support System for Heart Failure Diagnosis: INTELHEART Approach Towards Personalized Treatment Strategies. In: 2024 IEEE 24th International Conference on Bioinformatics and Bioengineering (BIBE) [Internet]. 2024 [cited 2025 Feb 22]. p. 1–5. Available from: https://ieeexplore.ieee.org/abstract/document/10820487

68 CardiovascularAISmart StethoscopeRemoteCardiacCarePediatrics [Internet]. Minttihealth. 2024 [cited 2025 Feb 22]. Available from: https://minttihealth.com/enhancing- cardiovascular-healthcare-the-role-of-ai-in-smart-stethoscopes-and-remote-cardiac-care-for- pediatrics/