Review Article

Systematic Review of Medical Devices with Technological Features for Measuring Lung Sounds from 2004 to 2024

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Abstract - Given the growing problem of respiratory diseases, which represent a significant burden of mortality globally, the main objective of this study was to analyze the scientific production of medical devices with advanced technologies for measuring lung sounds between 2004 and 2024. A systematic review was conducted using the Scoping Review technique, employing the Scopus database to identify relevant publications. The results reveal a significant increase in research, with notable contributions from countries such as India and the United States and a predominance of articles and conference presentations. Likewise, emerging technologies, such as neural networks and spectrograms, were identified, which improve diagnostic accuracy. This study suggests that adopting advanced technologies in measuring lung sounds can optimize the early diagnosis and management of respiratory diseases, highlighting the importance of innovation and international collaboration in this field.

Keywords - Medical devices, Lung sounds, Scopus, Technology, Measurement.

1. Introduction

Currently, 99% of the world's population consumes ambient air higher than the suggested quality standards, significantly compromising their well-being and quality of life [1]. In this sense, the prevalence of respiratory diseases places them as the third cause of death worldwide, which is represented by more than 9 million deaths per year [2]. The World Health Organization (WHO) indicates that these pathologies represent 13% of the annual mortality burden, representing a global challenge [3].

Chronic respiratory diseases are the most serious and generate a high number of deaths, with Chronic Obstructive Pulmonary Disease (COPD) responsible for 3.23 million of them and is especially prevalent in developing countries [4]. Likewise, tuberculosis is a re-emerging disease that affects more than 10 million individuals, which highlights its pathological potential, especially in patients with comorbidities such as the Human Immunodeficiency Virus (HIV) [5].

The Pan American Health Organization (PAHO) points out that chronic respiratory diseases lead to more than 500 thousand deaths in the region [6]. In relation to this, Honduras leads as the country with the highest mortality rate, with 59 deaths per hundred thousand people, a figure that does not differ much from other Latin American countries [7]. In this scenario, poverty and health access inequalities are the main mitigating factors for their prevalence [8].

In Peru, more than 2 million episodes of Acute Respiratory Infections (ARI) occur each year in children under 5 years of age and Loreto, with 22%, is the department with the highest prevalence [9]. For this reason, the Ministry of Health (MINSA) highlights the relevance of prevention and treatment in the face of increased respiratory disorders in the national territory [10]. It is also suggested to avoid pollution smoking in all its forms and promote healthy habits [11].

On the other hand, the COVID-19 pandemic has caused nearly 800 million confirmed cases and more than 7 million

deaths by 2023 [12]. Deaths are mainly caused by severe complications in the respiratory pattern that limit oxygenation capacity, as in acute respiratory distress syndrome. Therefore, early identification of lung sounds is crucial for the timely diagnosis and management of respiratory symptoms [13].

Lung sound is cyclically generated by airflow passage through the airways during inhalation and exhalation. These sounds are medically evaluated with the auscultation technique and the support of a stethoscope, considering parameters that include intensity, frequency and quality of breathing. Thus, lung sound alterations can indicate respiratory conditions, impairment, obstructions or underlying conditions [14].

In this sense, each respiratory pathology is differentiated by characteristics and representative sounds that guide the therapeutic approach; for example, COPD shows chronic airflow obstruction in the lungs, wheezing, snoring, and reduced gallbladder murmurs [15]. Similarly, in asthma, there are episodes of respiratory distress and wheezing audible from inflammation and narrowing of the airways, as opposed to the crackling sounds in pneumonia [16].

Complications of these disorders include progressive deterioration of lung function, extension to other systems, and reduced quality of life [17]. In the same way, the population with the highest risk of presenting this type of condition is made up of individuals of extreme age, a history of tobacco consumption, exposure to pollutants, family pathologies and conditions that compromise the state of health, such as immunosuppression of the immune system [18]. The prevention of respiratory diseases must be based on effective diagnostic techniques. With emerging technologies, these techniques have evolved beyond the traditional use of manual auscultation instruments [19]. Now, new devices are available that integrate auscultation methods with advanced technological tools. These modern devices combine the accuracy and sensitivity of manual auscultation with today's technology's analytical and data processing capabilities.

In the study by Frerichs et al. [20], a remote chest monitoring system was designed using wearable sensors to improve the health of people with lung diseases. The sample consisted of 50 healthy individuals randomly selected. This study employed a multimodal approach, using a vest with sensors to measure biosignals and gradually assessed ventilation, deep breathing, physical activity, and postures. The system proved functional, providing valid results on vital functions and postures and being safe and comfortable for users.

Research by Shing et al. [21] on detecting and classifying lung sounds for diagnosing respiratory pathologies developed an accurate method using Depth-

Separable Convolutional Neural Networks (DS-CNNs). A method that merges time and frequency properties achieved an average accuracy of 85.74%. In addition, it showed a higher deduction rate than imaging and common devices. This integration into AI-assisted wearables was shown to deliver high accuracy.

In the project by Azadeh et al. [22], sleep apnea of respiratory origin was addressed using an automated technique for its diagnosis and monitoring. The signals are segmented into sound and silent using the energy emitted by lung sounds. A procedure that allowed respiration, noise, snoring and oxygen saturation to be classified, evaluating their characteristics. In a sample of 66 people, complete nocturnal Polysomnography (PSG) was correlated with the system developed. The technique obtained sensitivity and specificity greater than 91% to differentiate snoring.

In the research by Jafarian et al. [23], lung sounds were analyzed using a color spectrograph, which processes the spectrum of emitted light, for respiratory monitoring. In addition, the study modified a miniature electret microphone with an anatomical adapter and amplified the signal to connect it to a spectrography program on a portable device. The results showed that the color patterns of the spectrogram markedly improved lung monitoring in individuals with respiratory pathologies. On the other hand, the problem raised demands an exhaustive evaluation with the help of investigative exploration resources. To this end, systematic review is one of the most effective tools since its development involves compiling and analyzing the existing literature on a topic of interest in a detailed and structured way to answer a research question [24]. In addition, its functionality includes the use of specific methodologies to enrich the analysis and systematization of scientific production.

Running a systematic review of our research is crucial for the early detection of lung diseases using cutting-edge medical devices with continuous improvements. This strategy facilitates the early identification of pathologies and contributes to developing evidence-based clinical guidelines. As a result, medical decision-making will be improved, and healthcare quality will be elevated, optimizing patient outcomes and strengthening clinical practice in general.

Considering the above, the main objective of this study is to analyze the scientific production related to medical devices with technological characteristics to measure lung sounds, provide a rigorous and updated analysis of the situation of current publications and determine trends in the scientific field. To this end, the following organization is proposed: Section 2 details the methodology used, and Section 3 shows the results obtained. Section 4 evaluates these results to formulate conclusions, and finally, the bibliography is shown.

2. Methodology

Initially, the different methodologies for managing information were analyzed, and the scoping review was considered the most appropriate for systematising keywords related to medical devices to measure lung sounds [25]. For this reason, the organization by stages begins with the bibliographic search in Scopus, as it is one of the most relevant databases [26]. In addition, the sample will be delimited utilizing inclusion and exclusion criteria to ensure the specificity of the selected information.

After that, the data were synthesized in a brief base that allowed the observation of trends, problems, gaps, and interests by extension. This approach is intended to comprehensively evaluate the literature on devices measuring lung sounds, maintaining a wide-ranging reference for further research and technological development.

2.1. Scoping Review

It is a systematic review methodology that identifies scientific production on an extensive topic or with a high degree of complexity to facilitate its management and subsequent analysis; this superiority in scope magnitude causes. Its process begins with defining a general question, the exhaustive search of the literature and selecting studies under adjustable criteria [27].

2.2. Flow Chart

It is a scheme based on symbols connected by lines for the detailed visualization of each procedure. It offers a clear and detailed picture of the processes and facilitates understanding the research [28]. This diagram describes the steps considered in the systematic review of medical devices for measuring lung sounds.
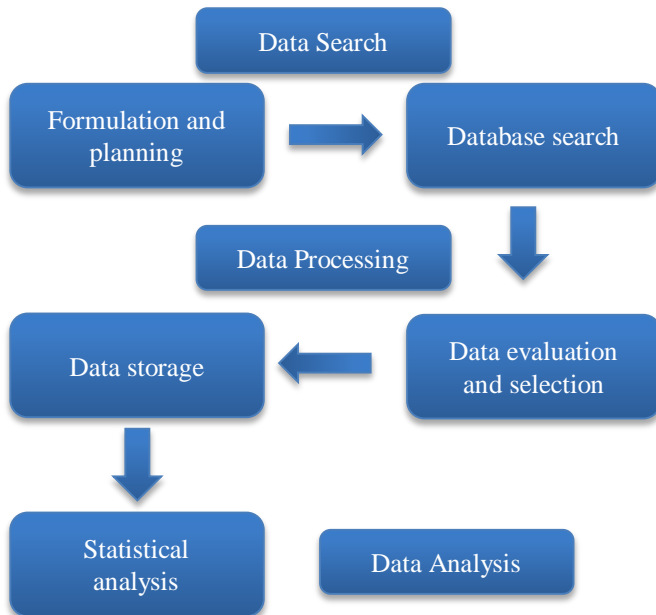

Fig. 1 Information search process

Figure 1 shows the diagram of the main stages proposed in this study, which are consecutive and codependent. The first is the search for data, which focuses on establishing a properly determined main objective for formulating structured questions with the support of specific keywords that favor obtaining better results. Then, the documents are carefully evaluated and selected to extract the most relevant data, summarized and evaluated in detail. Finally, with the formation of a well-defined base, statistical analysis can be carried out to establish patterns and trends with the variables.

In this way, a visual representation of the research stages offers various benefits, among which is the clarification of the methodology used, which reduces ramblings due to factors such as the use of technical terms, simplifying the understanding of the research. Likewise, this construction allows the study objective to be framed to visualize it during the phases.

2.3. Planning and Searching for Data

In the field of research on medical devices with technological characteristics to measure lung sounds for diagnosis and treatment of respiratory diseases, there are several prominent database platforms, among which Scopus is one of the most relevant [29]. This platform is distinguished by its exhaustive bibliographic categorization and wide acceptance in the scientific and academic community. The platform offers an intuitive tool and a dynamic interface, making it easy to search various research papers, including articles, journals, patents, conferences, and books [30].

In addition, each component of the Scopus interface is carefully designed to optimize the collection of relevant information, including the search bar, search filters, results, full-text links, charts and metrics, results export, alerts and tracking, and the analysis tool [31]. Using Scopus encourages exhaustive and focused analysis, improving the application of structured methodologies in this and other research. The detailed review supports increasing the benefits in the search and selection of documentation to guarantee the relevance and quality of the means used in the research [32].

Effective search in the Scopus database is aided by the availability of Boolean connectors, a logical resource that allows combining different terms and refining raw information. The available operators are AND, with which two or more terms are joined to find documents that contain all the specified words, OR requests the search for articles in which any of the requested terms are found; and AND NOT excludes words so that the results offered do not include documents that contain the excluded word(s).

2.4. Data Processing

The Scopus database provides groupings containing selected documents and uses them according to the users'

objectives, facilitating content distribution and access. One of the groups that can be recognized is "Open Access", which is predominantly used because it has open access to publications in three different scopes. The first is "Gold Open Access", which allows free access for all users from the moment of publication of the document since the monetary rate is covered by the authors or the institution to which they belong. The second is "Green Open Access", where a publication version can be accessed through an institutional repository. The third is "Hybrid Open Access", in which authors make a special payment to make their document freely accessible in a journal where the documents are generally paid. Another modality is "Subscription Access," which allows you to access scientific content through an individual or institutional subscription. Individuals who do not meet this requirement can access the required document by paying for one of the subscribed institutions. "Bronze Open Access" enables temporary or perennial free access to documents in private access journals. Finally, "Delayed open Access" provides free access to an article after a period in which the content is not accessible [33].

On the other hand, Scopus allows you to export search data in Comma-Separated Values (CSV) and BibTeX formats. The former is a simple structure used to store data in lists, spreadsheets, and databases. At the same time, the latter manages bibliographic sources, making it easier to obtain accurate data on articles, conferences, and books [34, 35]. CSV and BibTeX export not only organizes and manages information but also integrates it into reference management and data analysis systems, optimizing the workflow in research projects.

2.5. Data Analysis
The files from the previous stage were analyzed in CSV and BibTeX to be visualized using graphs, an essential resource for interpreting and understanding the data collected. These representations highlighted trends and patterns not evident in textual reviews, showing relationships between variables and providing a deeper understanding of the research context. In this sense, Scopus offers extensions to create pie charts, bar charts and line diagrams, simplifying interpretation and offering a clear perspective for researchers [36].

3. Results
Examining the data, results are proposed that highlight the significant parameters in documents of medical devices with technological qualities for the auscultation of lung sounds. Scopus is considered a reliable source for this type of study, it has facilitated the systematic investigation and appreciation of scientific publications, focusing on the 20 years between 2004 and 2024 as it is a period in which there is a marked increase in the number of publications, as will be shown below.

In addition, the categorization of documents under the modeling provided by Scopus has provided both a general and specific understanding of access to information, the different limitations detected, and their impact on the assessment of lung sounds. In addition, it has been shown that using Boolean operators in advanced analysis is essential for more effective results profiling.

3.1. Planning and Searching for Data
Thorough procedures must be implemented during planning and information gathering, which proved crucial to support the main objective. Applying the criteria described in the methodology, data available in Scopus on medical devices with technological characteristics to measure lung sounds were collected, excluding those non-technological devices and those used under conventional criteria.

The search algorithm retrieved from the Scopus database adapted according to the selection criteria is shown below:

(TITLE (lung AND sounds) AND TITLE (device) OR TITLE-ABS-KEY (design) OR TITLE-ABS-KEY (diagnosis) OR TITLE-ABS-KEY (prevention) OR TITLE-ABS-KEY (measurement) OR TITLE-ABS-KEY (detection) OR TITLE-ABS-KEY (auscultation) OR TITLE-ABS-KEY (respiratory AND diseases) OR TITLE-ABS-KEY (lungs) OR TITLE-ABS-KEY (portable) OR TITLE-ABS-KEY (development) OR TITLE-ABS-KEY (alteration) OR TITLE-ABS-KEY (medical AND equipment) OR TITLE-ABS-KEY (prototype)) AND PUBYEAR > 2003 AND PUBYEAR < 2025 AND (EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "NURS") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "BUSI") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "VETE") OR EXCLUDE (SUBJAREA , "ENVI"))

The Boolean operators that determine the main incidents are TITLE (lung AND sounds) and TITLE (device), both essential for the search for the rest of the information. The following configurations contain structures delimited by the OR connector, establishing a pattern in which terms can appear in the results, although not mandatorily.

Table 1 presents the results of the preliminary search, which comprises a total of 594 documents, underlining the valuable contribution of accessing Scopus for this research. The types of documents identified in this search are broken down as follows: 289 articles (48.65%), 265 conference papers (44.61%), 16 reviews (2.69%), 9 book chapters (1.52%), 8 letters (1.35%), 4 editorials (0.67%), 1 brief survey (0.17%), 1 note (0.17%), and 1 data article (0.17%).

Table 1. Types of documents

Document Type		
Document Type	Quantity	Percentage
Article	289	48.65%
Conference paper	265	44.61%
Review	16	2.69%
Book chapter	9	1.52%
Letter	8	1.35%
Editorial	4	0.67%
Shorts survey	1	0.17%
Note	1	0.17%
Data paper	1	0.17%

Table 2. Sorting by access type

Access Type	
Document Type	Quantity
All open access	166
Gold	82
Putting green	70
Bronze	35
Hybrid gold	21

The predominance of articles and conference papers reflects the importance of these formats in disseminating scientific and technological research. At the same time, reviews, book chapters, and other documents complement the knowledge base through critical analysis and synthesis of specific topics. This wide variety of documents evidences the diversity of formats available in Scopus and the ability of the database to provide a rich source of relevant information.

3.2. Data Processing

In processing publications from 2004 to 2024, the 594 documents found were re-evaluated. It was decided to maintain this number because the strict delimitation with Boolean operators used in the search was effective. Thus, this database maintains a comprehensive coverage and in-depth understanding of trends and developments in the field of study, so the application of additional filters is not considered necessary.

Table 2 presents the results of the number of documents classified according to their type of Open Access, indicating that some articles belong to more than one category. Among the documents found, 166 were identified in the category of "Total Open Access", 82 in "Golden Open Access", 70 in "Green Open Access", 35 in "Bronze Open Access", and 21 in "Hybrid Open Access".

In summary, the data collected are adequate and relevant to the research objectives, as shown in Table 1, where only scientific documents such as articles, conference papers, reviews, book chapters, letters, editorials, short surveys, notes, and data articles were considered valid. This selection ensures that the documents included are rigorous and provide

valuable information to the study, facilitating a deeper and more detailed understanding of the topics investigated.

3.3. Data Analysis

The information detailed below comes from the database of 594 documents. With the support of Scopus extensions activated through the API provided by the same platform, the visualization of graphs containing the study's main results has been facilitated. These graphical tools have allowed for a clear and accessible interpretation of the data, highlighting the relevant trends and patterns identified during the review.
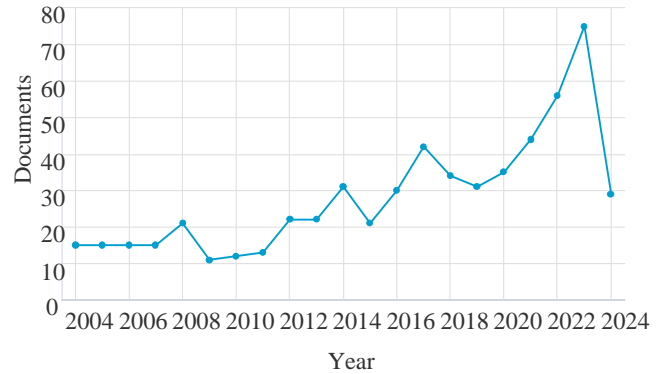

Fig. 2 Document by year

Figure 2 shows that the algorithm used began to generate results in 2004 when 15 publications were detected. During the first few years, the number of publications remained relatively constant.

However, in 2008, there was an initial increase to 21 publications, marking the beginning of sustained growth. From 2012, this increase became exponential, with 22 documents registered that year.

This trend continued, reaching 75 publications in 2023, and the figure continues to rise today. This pattern reflects substantial progress in research into devices with electronic features for measuring lung sounds.

Figure 3 illustrates the distribution of documents related to the measurement of lung sounds according to their country or territory of origin, highlighting those with the highest number of publications. The analysis covers 15 countries, placing India in the lead with 98 investigations, followed by the United States with 80, China with 67 and Japan with 57.

These four countries, together, account for more than half of the total publications, reflecting a significant concentration of research in these nations. The rest of the countries have limited contributions, including Peru, with only 3 publications.
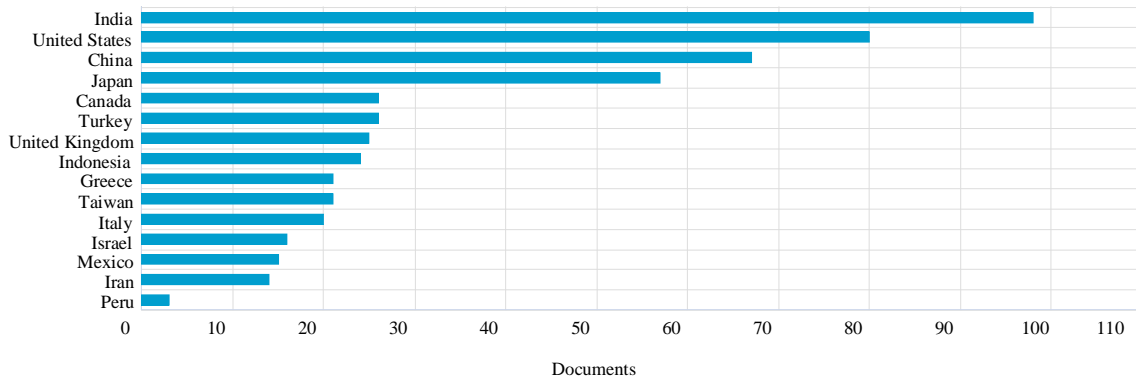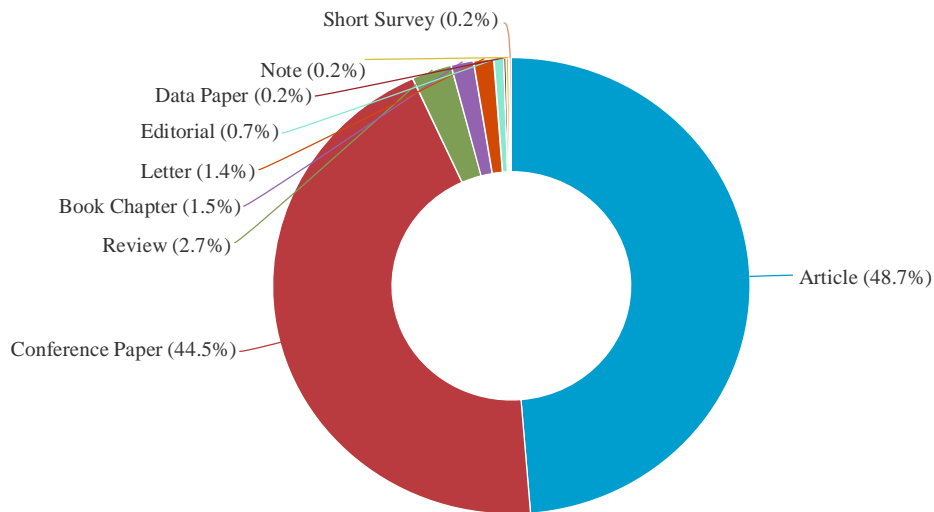
Fig. 3 Document by country or territory
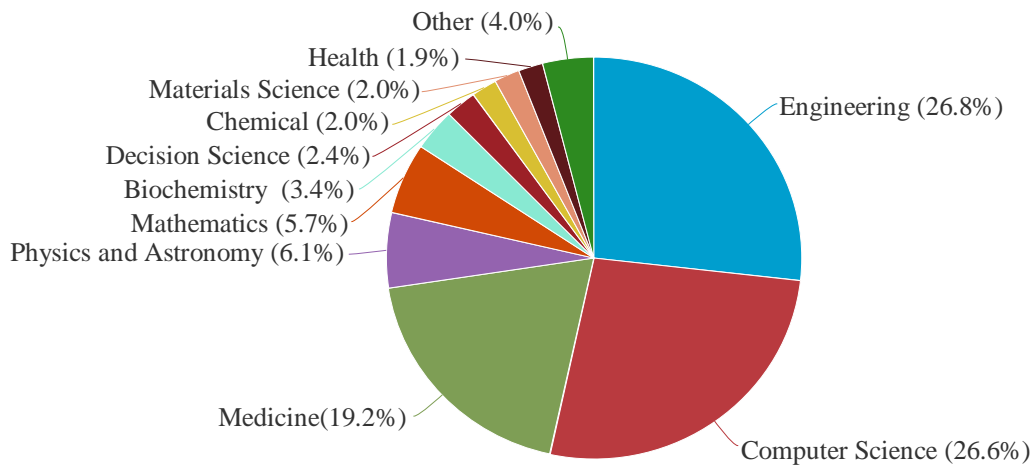

Fig. 4 Document by type

Fig. 5 Document by thematic area

Figure 4 shows the percentage corresponding to each document type, represented in a pie chart, based on the 594 publications analyzed. The predominant type of document is the article, with a significant 48.7%, equivalent to 287 publications. It is followed by presentations at congresses, constituting 44.5%, representing 262 documents. Together, the previous two represent more than 90% of the total. In contrast, the least representative documents include reviews, book chapters, letters, editorials, data documents, notes, and short surveys. These findings confirm the preeminence of articles and papers in the field of research, underlining their relevance in the dissemination of knowledge and the promotion of scientific advances.

Figure 5 presents the results selected according to the thematic area they belong to. Three main areas stand out: Engineering, Computer Science and Medicine. Engineering leads with the largest number of documents, reaching a total of 310, which represents approximately 26.8% of the total.

Similarly, Computer Science follows closely behind with 308 papers, constituting 26.6%. Medicine is third with 222 documents, equivalent to 19.2%. In addition to these main areas, other subject areas, such as Physics, Astronomy, and Mathematics, are also represented, although in smaller quantities.
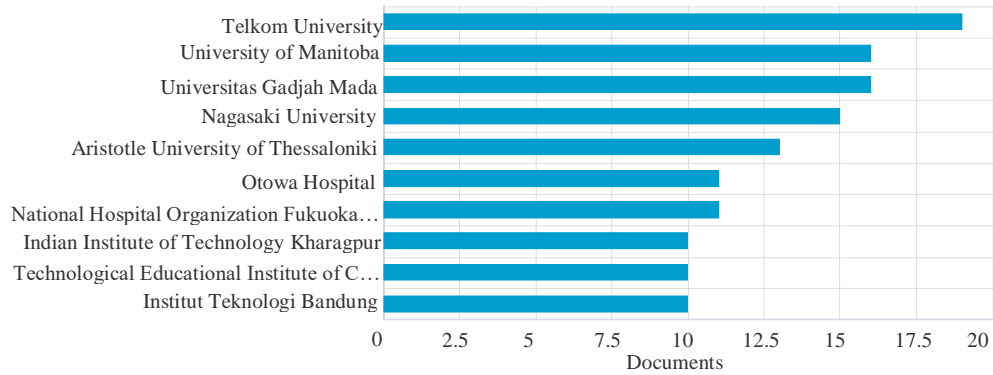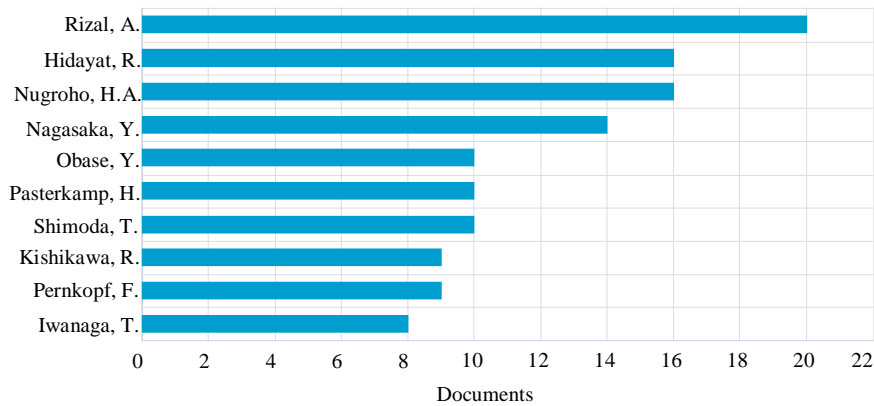

Fig. 6 Document by affiliation

Fig. 7 Document by author

According to Figure 6, the distribution of documents shows a notable variation depending on the type of affiliation. Telkom University leads the scientific production, contributing 19 of the publications found. It is followed by the University of Manitoba and Gadjah Mada Universitas, each with 16 documents. The University of Nagasaki contributed 15 documents, while the Aristotle University of Thessaloniki produced 13 documents. The Ottawa Hospital and the National Hospital Organization Fukuoka National

Hospital have contributed 11 documents each, followed by other entities with a lower percentage.

According to Figure 7, the author with the highest contribution in terms of number of publications is Rizal, A., who has produced 20 papers within the delimited period. Following closely, Hidayat, R. and Nugroho, H.A. have each generated 16 documents, demonstrating a notable contribution to research in this area. Other prominent authors include Nagasaka, Y., Obase, Y., Pasterkamp, H., and

Shimoda, T., who have made significant, though smaller, contributions. The diversity of authors and the number of publications by each one reflect a strong interest in the topic and research in general.

Figure 8 allows you to view the documents according to the sponsoring foundation to which they belong. Considering the funded documents, the National Natural Science Foundation of China stands out with the funding of 18 publications. It is followed by the National Institutes of Health, which endorsed 11 documents. The Singapore Economic Development Board and the Environmental Conservation and Restoration Agency each sponsored 6 documents. Other less representative sponsors have also contributed to the funding, although on a smaller scale, demonstrating a diversified interest in lung sound research.
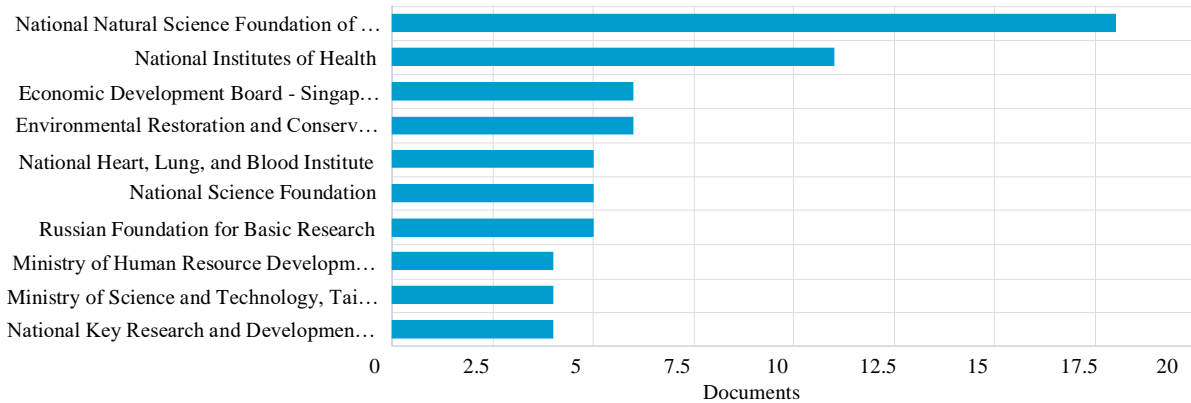

Fig. 8 Document by sponsoring foundation

4. Discussion and Conclusion

The study results have provided essential data to achieve the main objective, highlighting the importance of the Scoping Review methodology for a thorough and objective evaluation of technological medical devices [27]. This approach enabled the identification of advanced technologies, such as the sensor vest in [20], that significantly improve respiratory monitoring.

In the eastern countries, it was observed | a trend towards integrating new methods with advanced technologies. For example, [21] demonstrated that the DS-CNN method, with an accuracy greater than 85%, is effective for classifying lung sounds. In comparison, [22] achieved a sensitivity and specificity greater than 91% by automating the diagnosis of respiratory diseases. In addition, [23] confirmed that technological features, such as the spectrogram, improve the usefulness of medical devices.

The review included studies on medical devices with technological features for measuring lung sounds, published between 2004 and 2024, that employed advanced methodologies such as neural networks or spectrograms. Exclusion criteria applied to non-technological devices, studies without diagnostic or measurement innovations, and publications outside the scope of respiratory diseases.

On the other hand, the adequate application of Boolean operators allowed a precise collection of 594 documents, with articles and conference papers predominating, highlighting the quality of the search and the methodology used. In this sense, the 166 "Total Open Access" documents facilitated the research, demonstrating the importance of a well-defined search strategy that enriches data analysis.

The notable increase in research, with 75 publications in 2023, suggests a growing interest and greater investment in advanced medical technologies. This highlights the importance of innovation in diagnosing respiratory diseases and adopting technological tools in the medical field. The distribution by country, led by India with 98 publications, indicates that developing countries also contribute significantly to science. The inequality in the contribution of different countries underscores the need to promote research in regions with less scientific output.

The preeminence of articles and papers, which exceed 90% of the documents analyzed, highlights a clear preference of researchers for these formats, which are more appropriate due to the evaluation criteria they contain. Additionally, the visual representation in pie charts has facilitated the understanding of trends and highlighted the importance of formats in advancing scientific knowledge.

In addition, the distribution by thematic areas underlines the contribution of Engineering (310 publications) and Computer Science (308 publications) in the measurement of lung sounds, followed by Medicine, demonstrating the interdisciplinary nature of this research.

Institutional affiliations, such as Telkom University in Indonesia, and the production of prominent authors, such as Rizal, A., who leads with 20 publications, reflect collaboration and constant scientific production. Likewise, the diversity in funding sources, led by the National Natural Science Foundation of China with 18 publications, underscores the global importance of studying lung sounds and collaboration between organizations. Financial support and international cooperation are crucial to advance research and development of respiratory health technologies.

Finally, for future research, integrating technological features such as sensors, classification methods and spectrograms in lung sound monitoring devices is suggested. This integration will promote the design of modern and effective devices to prevent respiratory diseases. It will open new lines of research in fields such as medical engineering and technology, driving the development of innovative techniques for controlling respiratory diseases.

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