DEVELOPMENT AND APPLICATION OF A COMBINED DIGITAL PHONENDOSCOPE WITH AN INTEGRATED PULSE OXIMETER AND SUPPORTING SOFTWARE APPLICATION

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Abstract. *This article presents information on the technology of using a combined digital phonendoscope with an integrated pulse oximeter in the educational process. The study emphasizes its advantages in improving the organization, quality, and overall effectiveness of the learning process, which is essential for the development of students' professional competencies related to the diagnostic and therapeutic components of medical practice. The implementation of this technology contributes to more effective clinical training by enhancing the accuracy of auscultation, facilitating objective monitoring of physiological parameters, and supporting modern approaches to medical education.*

Keywords: *traditional phonendoscope, digital phonendoscope, combined phonendoscope, pulse oximeter, sound amplification, signal filtering, artifacts, educational process, telemedicine, artificial intelligence.*

Introduction

Ensuring the availability of qualified personnel at all stages of the formation and development of the healthcare system has long been regarded as one of the most important conditions for increasing the effectiveness of this multi-level system of medical care delivery to the population. It is widely recognized that the efficiency of this system, among other factors, largely depends on its provision with modern therapeutic and diagnostic technical equipment and technologies. This explains the considerable attention devoted to the widespread introduction of new equipment and innovative technologies into all areas of modern medicine and healthcare, which significantly contribute to improving the organization, quality, and efficiency of diagnostic, therapeutic, and preventive processes [2,8,10,13,17,21].

In this regard, the role and importance of introducing modern equipment and technologies into educational processes in the field of medicine are difficult to overestimate. Under the conditions of a steadily increasing prevalence of cardiovascular and respiratory diseases, the above-mentioned factors determine the relevance of developing technical devices and improving technologies aimed at enhancing the quality of training specialists in the fields of cardiology and pulmonology.

It is well known that as early as the beginning of the century, electronic phonendoscope stethoscopes [12,23,24], electronic stethoscopes [3,4], and multichannel electronic stethoscopes [13] were developed and created. These devices incorporate specialized units that allow high-resolution recording, storage, filtering, and processing of acoustic signals. Sounds obtained using digital stethoscopes can also be analyzed through computer software, thereby making the learning process more effective [5,7,8,9]. However, in practice both in clinical medical activities and in medical education the use of stethoscopes, particularly digital ones, remains relatively rare. In clinical practice, stethoscopes, including digital versions [8], are mainly used in obstetrics for

monitoring the fetal heartbeat within the uterus. In contrast, practicing physicians, academic staff, and medical students primarily use phonendoscopes. These devices enable the auscultation of heart sounds and murmurs, as well as respiratory sounds in the lungs and bronchi in both adults and children.

The main objective of using a phonendoscope is to characterize and assess the functional condition of the cardiovascular and respiratory systems through this widely available technical tool. The traditional approach using a conventional phonendoscope allows the functional state of each of these two systems to be evaluated separately. At the same time, the patient's condition and the need to provide urgent medical care often require physicians to rely on an integrated assessment of the functioning of both the cardiovascular and respiratory systems. The above considerations confirm the relevance of developing and creating a new technical device a combined digital phonendoscope with an integrated pulse oximeter along with the software necessary to ensure its effective operation.

Purpose of the study: The purpose of this study is to establish a theoretical and organizational framework for a combined digital phonendoscope with an integrated pulse oximeter equipped with a specialized integrated mobile application.

Research objectives

1. To conduct a sociological study of the opinions of medical students and practicing physicians regarding the feasibility of developing a combined digital phonendoscope with an integrated pulse oximeter.

2. To develop a set of specialized software programs mobile applications for the combined digital phonendoscope with a pulse oximeter, ensuring its targeted use in both educational and clinical diagnostic processes and enabling the following functions:

2.1. Reception of heart sounds and murmurs, as well as respiratory sounds from traditional auscultation points on the chest, and their filtering from artifacts.

2.2. Recording, storage, and transmission of auscultation data in real-time streaming format for prompt use in the organization of emergency and urgent medical care by family physicians, paramedics, patronage nurses, as well as trained patients or caregivers.

2.3. Playback of recorded auscultation data for use in diagnostic and educational processes.

2.4. Transmission of sounds to external speakers to amplify heart sounds, murmurs, and respiratory sounds during educational sessions and clinical consultations.

2.5. Transmission of data for use in telemedicine systems in the following formats:

2.5.1. "Attending physician – specialist consultants participating in a clinical consultation,"

2.5.2. "Patient – attending physician."

3. To determine the optimal duration of auscultation at specific cardiac and pulmonary points when using both traditional and combined digital phonendoscopes in the educational process, and to conduct a comparative evaluation of their effectiveness and diagnostic informativeness.

4. To develop a program and plan for testing the methodology and techniques of using the combined digital phonendoscope in the educational process during clinical training sessions.

5. To design a program and plan for testing the methodology and techniques of using the digital phonendoscope in order to improve the effectiveness of diagnostic processes in cardiology and pulmonology at the primary healthcare level.

Materials and Methods

The materials used to accomplish the research objectives consisted of the results of a questionnaire survey conducted among senior medical students (210 participants), master's degree students (155 participants), and practicing physicians of various specialties (65 participants). The theoretical foundation for the development of the combined digital phonendoscope with an integrated pulse oximeter was based on scientific studies addressing physical methods for the diagnosis of cardiopulmonary diseases [19], as well as the advantages of digital technologies particularly digital stethoscopes and their application in medical practice [1,8], including their use in the diagnosis of cardiovascular diseases [11,15] and respiratory system disorders [6,9,14]. In addition, the study took into account reports by several authors concerning not only the effectiveness [7,20] but also the capabilities and limitations of digital stethoscopes [16].

During the development of the technical component of the device, we relied on the circuit board design of a digital stethoscope previously proposed by other researchers [3,4,12,24]. It should also be noted that in the process of developing the digital phonendoscope and its accompanying software application, we were guided by fundamental dialectical principles, namely the law of the negation of the negation and the law of the transformation of quantitative changes into qualitative changes. During the testing and evaluation of the main stages of using the combined digital phonendoscope with an integrated pulse oximeter, the methods of observation, comparison, measurement, and logical analysis were applied.

Results and Discussion

The results of the sociological survey demonstrated that the majority of senior undergraduate students (182 respondents, 86.6%) and master's students (147 respondents, 95.0%) positively evaluated the necessity of developing and implementing a combined digital phonendoscope with an integrated pulse oximeter operating on the basis of a specialized mobile application. According to their opinion, such a solution would become an important factor in improving the quality of both theoretical and practical training in clinical disciplines. It should be particularly noted that 60 surveyed physicians (92.0%) also supported the view that the use of this technical device in medical practice would be highly significant, especially for establishing a diagnosis in emergency and urgent situations. They also emphasized the feasibility and potential of using this device for the comparative assessment of the quality and effectiveness of medical care provided over time.

In our development, unlike other existing analogues, a phonendoscope which is more commonly used in practical medicine was chosen as the primary device instead of a stethoscope, which is relatively less frequently used in routine practice. Furthermore, a pulse oximeter was structurally integrated with the phonendoscope within a single housing. A specialized software program in the form of a mobile application was developed to enable the simultaneous reception of incoming heart sounds and murmurs as well as respiratory sounds from the lungs, along with their filtering from external artifacts. Another specialized mobile application was designed to ensure the integration of data obtained from the two components of this system the digital phonendoscope and the pulse oximeter organized within a "network center."

This program also ensures the storage of heart sounds, murmurs, and respiratory sounds, their representation in the form of waveform graphs, and their transmission via a specially registered operational email to a highly qualified medical specialist. The implementation of another important function assigned to the combined digital phonendoscope with an integrated pulse oximeter the ability, when necessary, to reproduce heart sounds, murmurs, and respiratory

sounds both in their natural acoustic form and as waveform graphs is provided by a dedicated software module called “Playback.”

Within the framework of the research objectives, and based on data from scientific and practical literature concerning the structure and functions of a combined digital phonendoscope and a pulse oximeter, as well as additional recommendations proposed by the authors, the device was manufactured by engineering and technical specialists in the People’s Republic of China. The specialized mobile application ensuring the coordinated operation of the combined digital phonendoscope and pulse oximeter was developed by IT specialists on the basis of graphical designs and technical recommendations provided by the authors.

A program and plan were also developed for testing the methodology and techniques of using the digital phonendoscope with a pulse oximeter in the educational process during classes in clinical disciplines. The combined digital phonendoscope with an integrated pulse oximeter, along with the corresponding mobile applications, was tested and discussed in practice at the Department of Phthisiology and Pulmonology of Andijan State Medical Institute with the participation of students and the faculty members of the department. According to the participants, this diagnostic device will occupy a significant place among modern educational and technical tools used to enhance the quality and effectiveness of both theoretical and practical training related to the study of cardiac and pulmonary function.

In addition, the device contributes to the development of students’ competencies in consulting with specialists during the primary diagnostic assessment of patients, relying on clinical experience, and performing analytical evaluations with the assistance of artificial intelligence. According to the participants, the use of a combined digital phonendoscope with a pulse oximeter and a dedicated mobile application is also of particular importance in paramedical practice. This technology makes it possible to perform rapid assessment of the patient’s cardiovascular condition (heart sounds, murmurs, and rhythms) and respiratory status (SpO_2), facilitate the early detection of hypoxia, transmit clinical data to physicians remotely, support timely clinical decision-making, and improve the quality of medical care prior to hospitalization.

In order to develop a specialized circuit board for the combined digital phonendoscope with a pulse oximeter and the corresponding mobile applications ensuring its targeted use, a dedicated board design and software application were created. As a result, it became possible to receive heart sounds, murmurs, and respiratory sounds from auscultation points on the chest specified in the patient monitoring protocol. At the same time, in order to avoid obtaining distorted information regarding respiratory function, the protocol included an additional mandatory auscultation of the lungs along the lateral lines on both sides of the chest. It should be noted that the high-quality recording and storage of auscultation data were ensured by a specially designed module integrated into the device’s circuit board. The playback of recorded auscultation data was carried out using a dedicated technology operating through the software program “Playback.”

Practical experience demonstrated the feasibility of using the combined digital phonendoscope with an integrated pulse oximeter in the educational process after students have completed initial training in the university’s simulation laboratory. At this stage, students’ attention is drawn to the distinctive differences in heart sounds and murmurs between healthy individuals and patients with pathological conditions. It should be emphasized that this format of training is highly engaging for students. At the same time, students clearly understand that the heart sounds and murmurs they have listened to were reproduced on a mannequin, which naturally creates a desire to repeat the procedure on a real patient.

In this regard, the use of a combined digital phonendoscope with a pulse oximeter proves to be particularly appropriate, as it not only reinforces theoretical knowledge but also leaves a lasting impression of the specific heart sounds and murmurs observed in an actual patient. For this reason, subsequent training sessions devoted to the cardiovascular and respiratory systems are conducted using the combined digital phonendoscope with an integrated pulse oximeter. Such training sessions may be organized in several formats. In the first format, the instructor, at the patient's bedside, invites one of the students to perform cardiac auscultation using the combined digital phonendoscope with a pulse oximeter. The student begins auscultation at the traditional points on the chest. The detected heart sounds and murmurs are transmitted in real time via a mobile application to the smartphones of other students participating in the class. A more detailed review and discussion of the characteristics of heart sounds, murmurs, and pulmonary sounds in patients are then conducted in the classroom. In this setting, the sounds are reproduced through a standard speaker amplifier.

Participants involved in the testing of the combined digital phonendoscope with a pulse oximeter and its application technology noted that, compared with the traditional phonendoscope, this approach significantly reduces the time required for auscultation and collective discussion of a patient by a group of students. For example, auscultation of the heart by one student at a single listening point using a conventional phonendoscope requires approximately fifteen seconds. At five standard cardiac auscultation points, the procedure therefore takes about seventy-five seconds. If the examination is performed individually by ten students, the total time required increases to approximately 750 seconds.

Similarly, if it is taken into account that for a complete pulmonary auscultation one student requires about ten seconds at a single listening point, then examination at twelve points on the anterior chest, fourteen points on the posterior chest, and five points along both the right and left lateral sides of the thorax requires a total of approximately 460 seconds. If this value is multiplied by ten students, the total time required reaches 4,600 seconds. Naturally, in such circumstances a patient is not always willing to be examined by all ten students, especially one after another. For this reason, auscultation with a conventional phonendoscope is usually limited by the instructor to only one student, which significantly affects both the sequence and the overall effectiveness of the teaching session. This limitation becomes particularly evident when detailed and thorough discussion of the characteristics of heart sounds, murmurs, and respiratory sounds in a particular patient is required.

In such situations, the use of a combined digital phonendoscope with an integrated pulse oximeter becomes an essential solution for preventing these difficulties due to its functional capabilities described above. After performing auscultation of the patient, the instructor and students move from the hospital ward to the classroom, where the recorded heart sounds, murmurs, and respiratory sounds are discussed. Particular attention is paid to cardiac activity normal heart sounds in healthy individuals and pathological murmurs in patients as well as to respiratory sounds, including vesicular breathing in healthy individuals and bronchial breathing and additional abnormal sounds in patients, such as dry rales, moist rales, and crepitation.

Thus, digital phonendoscopes equipped with a pulse oximeter serve as an important tool in the study of diseases of the cardiovascular and respiratory systems. Their use in clinical training contributes to improving the quality of education and helps students develop essential practical skills. The data obtained through digital stethoscopes can be easily analyzed by students, which significantly enhances the effectiveness of the learning process.

At the present stage, the research is focused on developing a program and implementation plan, as well as testing the methodology and techniques for using the digital phonendoscope with a pulse oximeter to improve the efficiency of diagnostic processes in cardiology and pulmonology at the primary healthcare level. The program also предусматривает the transmission of clinical data for use within telemedicine systems in the following formats: “Patient - Attending Physician” and “Attending Physician-Specialist Consultants (participants of a clinical consultation).”

Conclusions and Recommendations

1. In the context of the growing importance of diagnostic methods in the early detection and treatment of cardiovascular diseases and respiratory disorders, the development, creation, and wide implementation of advanced technical devices in clinical practice are becoming increasingly relevant. This represents one of the most important priorities of modern medicine and healthcare.
2. The testing and evaluation of the combined digital phonendoscope with an integrated pulse oximeter developed by the authors, along with its accompanying mobile applications, demonstrated a high level of effectiveness in its application within the educational process.
3. The mass production of the combined digital phonendoscope with a pulse oximeter and its mobile application, as well as their provision to faculty members and students of higher and secondary specialized educational institutions, in addition to practicing healthcare professionals, will represent an important step toward creating highly effective conditions and improving the technologies used in both medical education and clinical practice.

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