Medical Device Innovation Workshop

AUSCULTATION
Problem Statement

Physicians must be able to hear heart and lung sounds to detect signs of cardiovascular disease. Stethoscopes are the primary tool used to detect sounds. Modern sensors and signal processing have enabled new approaches to auscultation.

Current Solutions

Articles

Patents
Stethoscope

The stethoscope is an acoustic medical device for auscultation, or listening to the internal sounds of an animal or human body. It is often used to listen to lung and heart sounds. It is also used to listen to intestines and blood flow in arteries and veins. In combination with a sphygmomanometer, it is commonly used for measurements of blood pressure. Less commonly, "mechanic's stethoscopes" are used to listen to internal sounds made by machines, such as diagnosing a malfunctioning automobile engine by listening to the sounds of its internal parts. Stethoscopes can also be used to check scientific vacuum chambers for leaks, and for various other small-scale acoustic monitoring tasks. A stethoscope that intensifies auscultatory sounds is called phonendoscope.

History

The stethoscope was invented in France in 1816 by René Laennec at the Necker-Enfants Malades Hospital in Paris. It consisted of a wooden tube and was monaural. His device was similar to the common ear trumpet, a historical form of hearing aid; indeed, his invention was almost indistinguishable in structure and function from the trumpet, which was commonly called a "microphone". The first flexible stethoscope of any sort may have been a binaural instrument with articulated joints not very clearly described in 1829.[1] In 1840, Golding Bird described a stethoscope he had been using with a flexible tube. Bird was the first to publish a description of such a stethoscope but he noted in his paper the prior existence of an earlier design (which he thought was of little utility) which he described as the snake ear trumpet. Bird's stethoscope had a single earpiece.[2] In 1851, Irish physician Arthur Leared invented a binaural stethoscope, and in 1852 George Cammann perfected the design of the instrument for commercial production, which has become the standard ever since. Cammann also wrote a major treatise on diagnosis by auscultation, which the refined binaural stethoscope made possible. By 1873, there were descriptions of a differential stethoscope that could connect to slightly different locations to create a slight stereo effect, though this did not become a standard tool in clinical practice.

The medical historian Jacalyn Duffin has argued that the invention of the stethoscope marked a major step in the redefinition of disease from being a bundle of symptoms, to the current sense of a disease as a problem with an anatomical system even if there are no noticeable symptoms. This re-conceptualization occurred in part, Duffin argues, because prior to the stethoscopes, there were no non-lethal instruments for exploring internal anatomy.
Rappaport and Sprague designed a new stethoscope in the 1940s, which became the standard by which other stethoscopes are measured, consisting of two sides, one of which is used for the respiratory system, the other for the cardiovascular system. The Rappaport-Sprague was later made by Hewlett-Packard. HP's medical products division was spun off as part of Agilent Technologies, Inc., where it became Agilent Healthcare. Agilent Healthcare was purchased by Philips which became Philips Medical Systems, before the walnut-boxed, $300, original Rappaport-Sprague stethoscope was finally abandoned ca. 2004, along with Philips’ brand (manufactured by Andromed, of Montreal, Canada) electronic stethoscope model. The Rappaport-Sprague model stethoscope was heavy and short (18–24 in (46–61 cm)) with an antiquated appearance recognizable by their two large independent latex rubber tubes connecting an exposed-leaf-spring-joined-pair of opposing "T"-shaped chrome-plated brass binaural ear tubes with a dual-head chest piece.

Several other minor refinements were made to stethoscopes, until in the early 1960s Dr. David Littmann, a Harvard Medical School professor, created a new stethoscope that was lighter than previous models and had improved acoustics. In the late 1970s, 3M-Littmann introduced the tunable diaphragm: a very hard (G-10) glass-epoxy resin diaphragm member with an overmolded silicone flexible acoustic surround which permitted increased excursion of the diaphragm member in a "z"-axis with respect to the plane of the sound collecting area. The left shift to a lower resonant frequency increases the volume of some low frequency sounds due to the longer waves propagated by the increased excursion of the hard diaphragm member suspended in the concentric accountic surround. Conversely, restricting excursion of the diaphragm by pressing the stethoscope diaphragm surface firmly against the anatomical area overlying the physiological sounds of interest, the acoustic surround could also be used to dampen excursion of the diaphragm in response to "z"-axis pressure against a concentric fret. This raises the frequency bias by shortening the wavelength to auscultate a higher range of physiological sounds. 3-M Littmann is also credited with a collapsible mold frame for sludge molding a single column bifurcating stethoscope tube[3] Wikipedia:Link rot with an internal septum dividing the single column stethoscope tube into discrete left and right binaural channels (AKA "cardiology tubing"; including a covered, or internal leaf spring-binaural ear tube connector).

In 1999, Richard Deslauriers patented the first external noise reducing stethoscope, the DRG Puretone. It featured two parallel lumens containing two steel coils which dissipated infiltrating noise as inaudible heat energy. The steel coil "insulation" added .30 lb to each stethoscope. In 2005, DRG's diagnostics division was acquired by TRIMLINE Medical Products.
Current practice

Stethoscopes are often considered as a symbol of healthcare professionals, as various healthcare providers are often seen or depicted with stethoscopes hanging around their necks. A 2012 research demonstrated that among several icons of healthcare, the stethoscope had the highest positive impact on the perceived trustworthiness of the practitioner [4].

Types of stethoscopes

Acoustic

Acoustic stethoscopes are familiar to most people, and operate on the transmission of sound from the chest piece, via air-filled hollow tubes, to the listener's ears. The chestpiece usually consists of two sides that can be placed against the patient for sensing sound; a diaphragm (plastic disc) or bell (hollow cup). If the diaphragm is placed on the patient, body sounds vibrate the diaphragm, creating acoustic pressure waves which travel up the tubing to the listener's ears. If the bell is placed on the patient, the vibrations of the skin directly produce acoustic pressure waves traveling up to the listener's ears. The bell transmits low frequency sounds, while the diaphragm transmits higher frequency sounds. This two-sided stethoscope was invented by Rappaport and Sprague in the early part of the 20th century. One problem with acoustic stethoscopes was that the sound level is extremely low. This problem was surmounted in 1999 with the invention of the stratified continuous (inner) lumen, and the kinetic acoustic mechanism in 2002. Acoustic stethoscopes are the most commonly used. A recent independent review evaluated twelve common acoustic stethoscopes on the basis of loudness, clarity, and ergonomics. They did acoustic laboratory testing and recorded heart sounds on volunteers. The results are listed by brand and model.

Electronic stethoscope

An electronic stethoscope (or stethophone) overcomes the low sound levels by electronically amplifying body sounds. However, amplification of stethoscope contact artifacts, and component cutoffs (frequency response thresholds of electronic stethoscope microphones, pre-amps, amps, and speakers) limit electronically amplified stethoscopes' overall utility by amplifying mid-range sounds, while simultaneously attenuating high- and low-frequency range sounds. Currently, a number of companies offer electronic stethoscopes. Electronic stethoscopes require conversion of acoustic sound waves to electrical signals which can then be amplified and processed for optimal listening. Unlike acoustic stethoscopes, which are all based on the same physics, transducers in electronic stethoscopes vary widely. The simplest and least effective method of sound detection is achieved by placing a microphone in the chestpiece. This method suffers from ambient noise interference and has fallen out of favor.
Another method, used in Welch-Allyn's Meditron stethoscope, comprises placement of a piezoelectric crystal at the head of a metal shaft, the bottom of the shaft making contact with a diaphragm. 3M also uses a piezo-electric crystal placed within foam behind a thick rubber-like diaphragm. Thinklabs’ Rhythm 32 inventor, Clive Smith uses an Electromagnetic Diaphragm with a conductive inner surface to form a capacitive sensor. This diaphragm responds to sound waves identically to a conventional acoustic stethoscope, with changes in an electric field replacing changes in air pressure. This preserves the sound of an acoustic stethoscope with the benefits of amplification.

Because the sounds are transmitted electronically, an electronic stethoscope can be a wireless device, can be a recording device, and can provide noise reduction, signal enhancement, and both visual and audio output. Around 2001, Stethographics introduced PC-based software which enabled a phonocardiograph, graphic representation of cardiologic and pulmonologic sounds to be generated, and interpreted according to related algorithms. All of these features are helpful for purposes of telemedicine (remote diagnosis) and teaching.

Electronic stethoscopes are also used with Computer-aided Auscultation programs to analyze the recorded heart sounds pathological or innocent heart murmurs.

**Recording stethoscopes**

Some electronic stethoscopes feature direct audio output that can be used with an external recording device, such as a laptop or MP3 recorder. The same connection can be used to listen to the previously recorded auscultation through the stethoscope headphones, allowing for more detailed study for general research as well as evaluation and consultation regarding a particular patient's condition and telemedicine, or remote diagnosis.[5]

**Fetal stethoscope**

A fetal stethoscope[citation needed] or fetoscope[citation needed] is an acoustic stethoscope shaped like a listening trumpet. It is placed against the abdomen of a pregnant woman to listen to the heart sounds of the fetus. The fetal stethoscope is also known as a Pinard's stethoscope[citation needed] or a pinard[citation needed], after French obstetrician Adolphe Pinard (1844–1934).

**Doppler stethoscope**

A Doppler stethoscope is an electronic device which measures the Doppler effect of ultrasound waves reflected from organs within the body. Motion is detected by the change in frequency, due to the Doppler effect, of the reflected waves. Hence the Doppler stethoscope is particularly suited to deal with moving objects such as a beating heart.[6] It was recently demonstrated that continuous Doppler enables the auscultation of valvular movements and blood flow sounds that are undetected during cardiac examination with a stethoscope in adults. The Doppler auscultation presented a sensitivity of 84% for the detection of aortic regurgitations while classic stethoscope auscultation presented a sensitivity of 58%. Moreover, Doppler auscultation was superior in the detection of impaired ventricular relaxation. Since the physics of Doppler auscultation and classic auscultation are different, it has been suggested that both methods could complement each other.[7][8] A military noise-immune Doppler based stethoscope has recently been developed for auscultation of patients in loud sound environments (up to 110 dB).
Stethoscope earpieces

Stethoscopes usually have rubber earpieces which aid comfort and create a seal with the ear improving the acoustic function of the device. Stethoscopes can be modified by replacing the standard earpieces with moulded versions which improve comfort and transmission of sound. Moulded earpieces can be cast by an audiologist or made by the stethoscope user from a kit.

Wear and maintenance

Stethoscope components are commonly made of plastic or rubber and may be damaged by solvents and other compounds used for cleaning, including alcohol and soap. The solvents may dissolve plasticizers that keep the components flexible. Lipids in the human skin will deteriorate and harden the tubing so it is good practice to use a cloth cover or make sure it is over the shirt collar. Stethoscopes with two-sided chestpieces are often lubricated where the chestpiece rotates around the stem, and must be re-lubricated periodically. If the lubrication is lost, the moving parts may grind against each other and destroy the fine mechanical tolerances required for the proper acoustic performance of the stethoscope. Cleaning the stethoscope will also remove lubricants, making periodic lubrication essential. Most lubricants must be kept away from rubber, vinyl, and plastic parts. For these reasons, only products that have been tested to be safe and effective for cleaning stethoscopes or lubricating similar medical instruments are normally used.

References


External links

• The Auscultation Assistant (http://www.med.ucla.edu/wilkes/intro.html), provides heart sounds, heart murmurs, and breath sounds in order to help medical students and others improve their physical diagnosis skills
• BBC: Smart stethoscope for detecting kidney stones (http://news.bbc.co.uk/2/hi/health/3963025.stm)
• Phisick (http://www.phisick.com/zmed.htm#stethoscopes) Pictures and information about antique stethoscopes
• Demonstrations: Heart Sounds & Murmurs (http://depts.washington.edu/physdx/heart/demo.html) University of Washington School of Medicine
• VCU Libraries Medical Artifacts Collection: Stethoscopes (http://dig.library.vcu.edu/cdm/search/collection/ mar/searchterm/stethoscopes/field/subjec/mode/all/conn/and/order/title)
Product Description
From the Manufacturer
The 3M™ Littmann® Cardiology III™ Stethoscope, one of the most recognized stethoscopes in the industry, features tunable diaphragms on both sides to deliver outstanding acoustic performance, diagnostic versatility and convenience for treating adult and pediatric patients.

**Tunable Diaphragm – the Heart of the Cardiology III Stethoscope**
With its innovative tunable diaphragm technology, the Cardiology III™ provides both bell (low frequency) and diaphragm (high frequency) capability during use. Switching between bell and diaphragm modes is as easy as a simple pressure change on the chestpiece, which means there is no need to remove, index and replace for same-site auscultation or turning over the chestpiece. This time-saving feature allows for focus on the patient. The diaphragm on the small side is easily removable and, with the included nonchill bell sleeve, converts to a traditional open bell for capturing low frequencies. The Cardiology III™ stethoscope is used by students and medical professionals such as cardiologists, pediatricians, and other healthcare providers to identify, listen to, and study cardiac, lung, and other body sounds in adult, pediatric patients. The diaphragm on the small side is easily removable and, with the included nonchill bell sleeve, converts to a traditional open bell for capturing low frequencies. The Cardiology III™ stethoscope is used by students and medical professionals such as cardiologists, pediatricians, and other healthcare providers to identify, listen to, and study cardiac, lung, and other body sounds in adult, pediatric patients. Resilient tubing folds tightly for pocket portability and retains its shape while patented Snap Tight Soft-Sealing Eartips help form an effective acoustic seal. The anatomically correct headset is angled to channel sound and enhance listening comfort while the nonchill rim and diaphragm provide patient comfort. The Cardiology III™ is made in the USA; product and package are latex-free and come complete with a non-chill bell sleeve, small and large eartips, and instructions.

**What is a Stethoscope?**
Stethoscopes are diagnostic instruments that amplify sounds made by the body from the heart, lungs, abdomen and intestinal tract, or other body sites. A stethoscope is used to detect and study internal systems, such as fetal development, blood flow or blood pressure (BP), and respiration, and sounds, such as cardiac, venous, arterial, pulmonary, and uterine. Stethoscopes typically have Y-shaped rubber tubing that allows sound to travel from the chestpiece to the eartips. An open bell detects low frequency sounds, and a diaphragm detects high frequency sounds. A stethoscope can come as single, double (dual), or triple-head. Binaural stethoscopes are used with both ears, and single stethoscopes work with one ear. Differential stethoscopes are double-head, and allow sound comparison between different body sites. Non-electronic, also called mechanical or acoustic, stethoscopes transmit sound through hollow tubing to a listener’s ear. Stethoscopes are used by students and a wide array of healthcare providers including physicians, nurses, and veterinarians, as well as specialists such as cardiologists, pediatricians, gastroenterologists, pulmonologists, and respiratory professionals in hospital, clinical, or other healthcare facilities.
With the TeleSteth™ System, you can easily incorporate the outstanding performance of Littmann sound quality into your telemedicine program. Hear it as if you were there.

Anytime, anywhere collaboration
Share heart, lung and other body sounds with colleagues located across the globe. Sounds are transmitted via a secure internet connection using the 3M TeleSteth™ System.

Remote evaluation
The revolutionary technology behind the TeleSteth™ System allows you to evaluate patient sounds remotely in real-time during an exam.

Easy access.
The TeleSteth™ System is designed to be accessed from a user’s PC through the internet.

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The TeleSteth™ System allows you to conduct remote auscultations anywhere you have access to a high-speed internet connection.

The flexible, web-based architecture allows you to log onto the 3M Littmann TeleSteth™ System site where you can listen to a patient at a remote site using real-time live streaming.

How the TeleSteth™ System Works
Description

iStethoscope Pro turns your iPhone into a stethoscope, allowing you to listen to your heartbeat and see your heart waveform, or listen to other quiet sounds around you. As seen on TV around the world!

What's New in Version 1.04

Version 1.04 requires firmware 4.0 or above. It is compatible with iOS 7 and iPhone 5S. The program is smaller and faster to launch. There is a new and clearer help button which redirects to the online help pages. Buttons now glow when pressed.

Customer Ratings

Current Version:

Average Rating: 4

All Versions:

Average Rating: 3

More iPhone Apps by undercover scientist software

iStethoscope Pro
View In iTunes
CADence™ is designed to detect functionally significant coronary blockage through an innovative, non-invasive, radiation-free test.
Thinklabs helps you visualize and record heart sounds with your iPhone or iPod touch. (2nd generation)
The App sets a new standard for medical device user interfaces, using iPhone’s outstanding multi-touch interface.

Features:
- Record and Display waveforms and spectrogram in real time.
- Scroll and Zoom In/Out using multi-Touch user interface.
- Edit Sounds on-screen.
- Save Recorded sounds.
- Email Sounds and Images, along with notes.

Hardware - stethoscope and input device
To listen to heart sounds, an electronic stethoscope is required. The Thinklabs Digital Stethoscope ds32a+ has been tested with the iPhone and iPod Touch (2nd generation). An external Microphone for iPod / Works with iPhone audio input device with audio input jack is required in order to connect the stethoscope to the iPod (2nd generation). We recommend the Belkin TuneTalk.

Contact us at Apps@thinklabsmedical.com or call 800-918-1088 for further assistance and questions about Stethoscope App.

Download the User Manual (pdf)
Computerized Lung Sound Analysis as diagnostic aid for the
detection of abnormal lung sounds: a systematic review and
meta-analysis

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Abstract

Rationale—The standardized use of a stethoscope for chest auscultation in clinical research is
limited by its inherent inter-listener variability. Electronic auscultation and automated
classification of recorded lung sounds may help prevent some these shortcomings.

Objective—We sought to perform a systematic review and meta-analysis of studies
implementing computerized lung sounds analysis (CLSA) to aid in the detection of abnormal lung
sounds for specific respiratory disorders.

Methods—We searched for articles on CLSA in MEDLINE, EMBASE, Cochrane Library and
ISI Web of Knowledge through July 31, 2010. Following qualitative review, we conducted a
meta-analysis to estimate the sensitivity and specificity of CLSA for the detection of abnormal
lung sounds.

Measurements and Main Results—Of 208 articles identified, we selected eight studies for
review. Most studies employed either electret microphones or piezoelectric sensors for
auscultation, and Fourier Transform and Neural Network algorithms for analysis and automated
classification of lung sounds. Overall sensitivity for the detection of wheezes or crackles using
CLSA was 80% (95% CI 72–86%) and specificity was 85% (95% CI 78–91%).

Conclusions—While quality data on CLSA are relatively limited, analysis of existing
information suggests that CLSA can provide a relatively high specificity for detecting abnormal
lung sounds such as crackles and wheezes. Further research and product development could
promote the value of CLSA in research studies or its diagnostic utility in clinical setting.

Keywords

Pneumonia; Respiratory disorders; Electronic auscultation; Lung sound analysis
INTRODUCTION

The stethoscope is used by clinicians to aid in the diagnosis of respiratory disorders; however, application of the stethoscope in research studies has been limited due to the inherent inter-observer variability and subjectivity in the interpretation of lung sounds (1). The diagnostic value of auscultation in detecting abnormal lung sounds in clinical research could be improved if implemented using an objective and standardized approach to interpretation. Computerized analysis of recorded lung sounds may offer a systematic approach to the diagnosis of different respiratory conditions via automated classification of acoustic patterns.

Computerized lung sound analysis involves recording the patient’s lung sounds via an electronic device, followed by computer analysis and classification of lung sounds based on specific signal characteristics. Auscultation typically takes place in a clinic setting where there could be multiple sources of ambient noise. Acoustic auscultation, however, is generally limited by poor signal transmission due to noise, tubular resonance effects, and greater attenuation of higher frequency sounds (2). This is an important factor to consider in pulmonary auscultation because lung sounds are mostly characterized in the higher frequency spectrum ranging from 50 Hz to 2500 Hz. On the other hand, electronic auscultation has the advantage of signal amplification and ambient noise reduction leading to increased signal-to-noise ratio along with its independence on human ear sensitivity to different acoustic frequencies (2). Rapid advancement in electronics and computer technology in recent years has increased research interest in automated classification of lung sounds among pulmonary researchers and has the potential to reduce software and hardware costs. Computerized lung sound analysis is a powerful tool for optimizing and quantifying electronic auscultation information based on the specific lung sound spectral characteristics (3,4). The Fourier transform is the most commonly used spectral analysis algorithm to provide information on the frequency components of a signal. Neural network, a machine learning algorithm for feature recognition and classification, has been used for classification of different lung sounds based on the features selected from frequency decomposition and associated statistical parameters (5).

We sought to perform a systematic review on computerized lung sound analysis and investigate its diagnostic utility in classifying recorded auscultatory findings. Our primary objective was to estimate the overall sensitivity and specificity of computerized lung sound analysis algorithms for detection of abnormal lung sounds based on currently available studies.

METHODS

Systematic Review Methods

Two investigators (AG, CGS) conducted independent literature searches using MEDLINE and EMBASE until July 31, 2010. Additional studies were obtained from references of identified studies, the Cochrane Library and the ISI Web of Knowledge. We searched for studies relating to use of chest auscultation and computer algorithms for automated detection and classification of lung sounds. Keywords included “pneumonia”, “acute lower respiratory infections (ALRI)”, “lung auscultation”, “electronic auscultation”, “Acoustic signal processing”, “computerized lung sound analysis”, “automated classification of lung sounds”, “crackle detection”, “wheeze detection” and “World Health Organization guidelines”. Literature search was based on corresponding Medical Subject Headings (MeSH) suggested in the MEDLINE database. We restricted our search to English because this was the only language for which both investigators were fluent. We excluded case reports or manuscripts not based on original research.

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The two reviewers independently reviewed and compared the resulting list of relevant articles and determined the eligibility of the full report. We evaluated each of the included studies for the method of electronic auscultation and the analytical approach used for the classification of lung sounds. We rated the quality of the studies based on the Newcastle-Ottawa Quality Assessment Scale (6). We followed the Meta-analysis of Observational Studies in Epidemiology guidelines (7).

**Biostatistical Methods**

Both reviewers individually extracted data from selected studies and compared outcomes for validation. Data from each selected study were summarized in a contingency table that compared CLSA performance against the gold standard diagnosis (i.e., chest radiography or clinical diagnosis). Four studies were selected for qualitative review only because they did not provide sufficient data to construct a contingency table (8, 9) or did not employ comparable methodology for statistical computation of sensitivity and specificity (10, 11), e.g. used number of crackles rather than number of cases and controls. We estimated overall sensitivity and specificity from the four studies selected for meta-analysis using a fixed-effects model (1, 12-14). We assessed for statistical heterogeneity between studies using Cochrane Q-tests and I²-values. We calculated a summary receiver operating characteristic (ROC) curve using standard techniques. We used R (www.r-project.org) for statistical analysis.

**RESULTS**

**Overview of the Literature Search**

We identified 208 articles via our initial search. After reading the abstract and methodology, we selected 40 articles for further review. Based on a detailed review of these 40 studies, we selected a total of 12 studies that had relevant methodology for qualitative discussion (1, 8-18). Duplicate articles were discarded which led to identification of eight studies for systematic review out of which only four studies had sufficient quantitative information for a meta-analysis (Table 1).

**Characteristics of Selected Studies**

All but one of the selected studies was conducted among adult populations from a clinical setting, either from an intensive care unit or a community hospital. Rietveld et al. recruited children and adolescents diagnosed with asthma. All of the studies were from middle- and high-income countries. Guntupalli et al. recruited subjects with asthma. Murphy et al., Mor et al., and Ono et al. recruited subjects with pneumonia. Waitman et al. and Kahya et al. selected patients with abnormal lung sounds upon auscultation.

Three studies specifically conducted computerized lung sound analysis for classification of wheezing (9-11), two analyzed crackles (12,14) and three analyzed both wheezes and crackles (1,10,13). Murphy et al. included a customized pneumonia score to scale the diagnosis of pneumonia which included the number of crackles identified in the respiratory cycle. Kahya et al. also included a customized crackles parameter, based on the duration of crackles during a respiratory cycle. Both studies indicated that inclusion of additional parameters like the number of crackles improved sensitivity and specificity of the computerized lung sound algorithm in classifying different lung sounds. Kahya et al. found an increase in sensitivity and specificity from 80% to 95% and 80% to 90%, respectively during the inspiratory phase, and found an improvement in specificity from 85% to 95% during the expiratory phase.
We observed minimal heterogeneity in recording devices and automated detection and classification algorithms employed in the eight studies. Five studies used microphones for electronic auscultation (1, 8, 10, 12, 14) and two used piezo-electric sensors (13, 17). Riella et al. used lung sounds available electronically from different online repositories and indicated the common usage of a contact accelerometer for recording though the authors did not provide information on the recording setting. Most of the studies selected one or four breath cycles segmented into inspiratory and expiratory phases with average recording duration ranging from 3 to 20 seconds. Mor et al. was the only study that specified instructing the patients to take deeper breaths than normal during recording which took place in a quiet but not sound proof room. Ono et al. was the only study that specified recording lung sounds in a sound proof room.

Five studies employed Fourier transform algorithms for lung sound classification (Table 1). Two studies used derivatives of Fourier Transform namely the Short-Time Fourier transform and Wavelets. One study used Time-Expanded Waveform Analysis and acoustic power analysis. Three included the Neural Network algorithm. One employed a k-Nearest Neighbor algorithm whereas two others classified lung sounds based on a two-dimensional gray-scale imaging system called vibration response imaging.

Quality of selected studies

Based on the Newcastle-Ottawa Quality Assessment Scale, Murphy et al. and Mor et al. each scored an average of 7.5, Ono et al. scored an average of 6.5, Guntupalli et al. scored an average of 4.5, whereas Rietveld et al., Waitman et al. and Kahya et al. each scored an average of 4. Riella et al. did not meet any of the Newcastle-Ottawa Quality Assessment Scale criteria. While all of the selected studies, except for Riella et al., provided a detailed description on inclusion criteria for their cases and applied the same study design for both the cases and the controls, only two studies provided information on selection criteria for controls (1, 14) and none required post-intervention responses from the subjects.

Meta-analysis

All four studies included for meta-analysis provided more than one dataset based on the data collection methodology. Ono et al. reported results from two independent observers, B and D. We randomly selected data from Observer B to be included in the meta-analysis. A sensitivity analysis using data from Observer D yielded similar results (data not shown). Mor et al. also conducted two separate analyses, one where the physician was blinded to patient information and one with patient information provided. We decided to use the blinded analysis due to the potential for diagnosis bias. Murphy et al. provided a separate statistical dataset for a learning sample and a test sample for use in the Neural Network algorithm employed for automated classification. We decided to use the data from the test sample in our analysis. Kahya et al. provided results for various parameters used in the analysis. Subgroup statistical analysis in the Kahya et al. study included data during the inspiratory versus the expiratory phases. Based on the significance of these two respiratory phases in the pathology of pneumonia, we decided to include inspiratory and expiratory separately in our meta-analysis.

In Table 2, we display the data we obtained from our review of the four studies included in the meta-analysis. Sensitivity and specificity for the selected studies varied from 70% to 95% and from 80% to 95%, respectively. The CLSA algorithm had an overall sensitivity of 80% (95% CI 72–86%, Figure 2) and an overall specificity of 85% (95% CI 78–91%, Figure 3). We display the ROC curve for studies included in the meta-analysis in Figure 4. Q-values for overall sensitivity and specificity were 4.9 (p=0.30) and 3.1 (p=0.55), respectively; I² values were 18% (95% CI 0–83%) and 0% (95% CI 0–73%), respectively.
DISCUSSION

Computerized analysis of recorded lung sounds may be a promising adjunct to chest auscultation as a diagnostic aid in both clinical and research settings. In our meta-analysis, we found that computerized lung sound analysis performs at a relatively high level of sensitivity and specificity in a small number of studies. Overall sensitivity for the detection of abnormal lung sounds using computerized lung sound analysis was 80% and overall specificity was 85%.

Our systematic review revealed, however, that there is a lack of standardization across studies in the methods used for lung sound recording, computer algorithms for signal analysis and statistical methods for outcome analysis. For example, recording lung sounds in a noisy clinic versus a quiet research room would demand a more rigorous post-processing technique to combat the noise present in the acoustic signal and the efficiency of the classification algorithms would vary accordingly. Such inconsistency not only leads to difficulty in interpreting and translating study outcomes but also has prevented commercialization of computerized lung sound analysis devices (16). Further research is needed to address the effectiveness of specific combinations of electronic devices and computing algorithms in clinical and community settings. In the advent of electronic auscultation and advanced signal processing techniques, Andres et al. has initiated a collaborative project, “Analyse des Sons Auscultatoires Pathologiques” (ASAP), a French national program that aimed to develop a database of objective definitions of auscultation sounds characteristic of certain pathologies, standardized formats of lung sound recordings and storage to facilitate exchange of information among health care providers (17). Likewise, Sovijarvi et al. (16, 18) has developed a set of Computerized Respiratory Sound Analysis (CORSA) guidelines to standardize the definitions and terminologies used in computerized lung sound analysis. Further evaluation and advancement of ASAP and CORSA guidelines may help standardize computerized lung sound analysis techniques and definitions and promote its research and development.

The selection of an appropriate signal processing technique is important in improving the diagnostic quality of the algorithm. A growing number of studies have analyzed the efficacy and efficiency of spectral analysis algorithms in detecting and classifying wheezes and crackles. Lung sounds range in frequency between 50 Hz and 2500 Hz, and tracheal sounds can reach values up to 4000 Hz (3). Normal breath sounds have their main frequency band between 200 Hz and 250 Hz, and normal tracheal sounds range from 850 Hz to 1000 Hz (19). Abnormal breath sounds have higher and wider frequency band; continuous wheezes lie between 100 Hz and 2500 Hz with a dominant frequency between 100 Hz and 1000 Hz, and have a duration greater than 100 milliseconds (3, 16). Crackles are in the frequency range of 100 Hz to 2000 Hz or even higher, with two cycle duration of greater than 10 ms for coarse crackles and two cycle duration of less than 10 ms for fine crackles (3, 16). Therefore, frequency analysis and quantification of biological signals such as lung sounds provides information that is not readily available in the time-domain and thereby allows such signal processing algorithms to automatically distinguish between normal and abnormal lung sounds. Inclusion of a broader spectrum of detection parameters, from both the time and the frequency domains might further improve the sensitivity and specificity of the computerized lung sound analysis algorithm in detecting pneumonia and other respiratory disorders. Spectral analysis with inclusion of lung sound related features such as crackle counts and duration, specific inspiration versus expiration, was found to improve the diagnostic accuracy (1, 12).

Our study is limited by the small number of available studies on the clinical utility of auscultation and computerized lung sound analysis for the diagnosis of abnormal lung
sounds. Selected studies widely involved adult populations with the exception of Rietveld et al. (8) who included children and adolescents with a mean age of 12 years. Gross et al. (15) indicated that the spectral components of lung sounds have slight variance among different age groups, particularly in infants and children. Therefore, the findings of this study could not be directly applied to a pediatric population.

In summary, electronic auscultation coupled with computerized lung sound analysis has the potential to improve diagnostic yield of pulmonary disorders in both clinical and research settings. More studies are needed to characterize recorded lung sounds, particularly in children. Furthermore, our study identified the need to address standardization of methodology and analytical methods across studies. This technology, however, faces a significant challenge before achieving clinical acceptance due to aforementioned lack of standardized clinical trials and lack of diagnostic validity.

Acknowledgments

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REFERENCES


Figure 1. Sensitivity Plot for Studies Included in Meta-Analysis
The sensitivity of individual studies are represented by squares and corresponding 95% confidence intervals are represented by segments. The overall sensitivity and corresponding 95% confidence intervals represented by a diamond. The center of the diamond is the overall sensitivity and the length of the diamond is the 95% confidence interval.
Figure 2. Specificity Plot for Studies Included in Meta-Analysis

The specificity of individual studies are represented by squares and corresponding 95% confidence intervals are represented by segments. The overall specificity and corresponding 95% confidence intervals represented by a diamond. The center of the diamond is the overall specificity and the length of the diamond is the 95% confidence interval.
Figure 3. Summary Receiver Operating Characteristics Plot for CLSA algorithms
Individual studies are displayed as circles. Overall sensitivity and specificity is displayed as a cross.
Table 1

Description of Characteristics of Selected Studies

<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Location</th>
<th>N</th>
<th>Age Range (years)</th>
<th>Gender Ratio (M:F)</th>
<th>Methodology</th>
<th>Case definition</th>
<th>Recording Device</th>
<th>Algorithm</th>
<th>Chest sound evaluated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rietveld et al. (1999)</td>
<td>Amsterdam, Netherlands</td>
<td>Cases: 50</td>
<td>7 – 18 (mean = 12.1, SD=2.9)</td>
<td>N/A</td>
<td>Asthma cases were recruited upon physicians’ referral whereas controls were enrolled via advertisements on newspapers in the Netherlands. Two experienced examiners conducted data analysis blinded to patient information. Case severity was verified by British lung physicians.</td>
<td>Asthma</td>
<td>Microphones</td>
<td>Fourier Transform Neural Network</td>
<td>Wheezing</td>
</tr>
<tr>
<td>Waitman et al. (2000)</td>
<td>Nashville, Tennessee</td>
<td>Cases and controls: 17</td>
<td>19 - 75</td>
<td>11:6 (cases and controls)</td>
<td>Lung sounds were collected from patients admitted in the Neurocritical Intensive Care Unit at Vanderbilt University Hospital and audio tapes used to train their clinicians. Two physicians conducted data analysis in a quiet environment blinded to patient information.</td>
<td>Pathological lung sounds</td>
<td>Microphones</td>
<td>Fourier Transform Neural Network</td>
<td>Crackles, wheezes, pneumonia, pleural rub, squawks, stridor</td>
</tr>
<tr>
<td>Murphy et al. (2004)</td>
<td>Boston, MA</td>
<td>Cases: 100</td>
<td>69 ± 18</td>
<td>Cases: 42:58</td>
<td>Subjects were recruited from the community teaching hospital in Boston, MA. Cases were confirmed by radiographic findings that were evaluated by two blinded, independent observers. Cases and controls were matched based on their age.</td>
<td>Pneumonia confirmed with radiographic evidence</td>
<td>Microphones</td>
<td>Time Expanded Waveform Analysis, Acoustic Power Analysis</td>
<td>Crackles, rhonchus, wheeze –used to generate an “acoustic pneumonia score”</td>
</tr>
<tr>
<td>Mor et al. (2007)</td>
<td>Israel</td>
<td>Pneumonia: 20</td>
<td>56 ± 17</td>
<td>Controls: 57 ±15</td>
<td>Subjects were recruited from three health service centers and one medical center in Israel. Two trained physicians conducted data analysis blinded to patient clinical information.</td>
<td>Radiologically and clinically confirmed diagnosis of pneumonia or pleural effusion</td>
<td>Piezo-electric sensors</td>
<td>Fourier Transform, Vibration Response Imaging (VRI)</td>
<td>“Normal” vs “Abnormal”</td>
</tr>
<tr>
<td>Kahya et al (2008)</td>
<td>Istanbul, Turkey</td>
<td>Cases: 20</td>
<td>99.8 ± 14.2</td>
<td>Cases: 10:10</td>
<td>Subjects were recruited from the pulmonary clinic of the Cerrahpasa Medical School of Istanbul University.</td>
<td>Respiratory disease</td>
<td>Air-coupled electrets microphone</td>
<td>Wavelet Transform k-Nearest Neighbor</td>
<td>Crackles</td>
</tr>
<tr>
<td>Guntupalli et al. (2008)</td>
<td>Houston, TX</td>
<td>Cases: 7</td>
<td>28 - 75</td>
<td>N/A</td>
<td>Subjects were recruited from two different institutions in Houston, TX. Three physicians conducted signal analysis blinded to patient clinical information. Analysis was based on 100 sound signal</td>
<td>Asthma and COPD</td>
<td>Piezo-electric sensors</td>
<td>Fourier Transform, Vibration Response Imaging (VRI)</td>
<td>Wheeze</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Study (year)</th>
<th>Location</th>
<th>N</th>
<th>Age Range (years)</th>
<th>Gender Ratio (M:F)</th>
<th>Methodology</th>
<th>Case definition</th>
<th>Recording Device</th>
<th>Algorithm</th>
<th>Chest sound evaluated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ono et al. (2009)</td>
<td>Tokyo, Japan</td>
<td>Cases: 21 Controls: 10</td>
<td>Cases: 65.7 ±11.0 Controls: 54.5 ±14.3</td>
<td>Similar in the two groups</td>
<td>Subjects were recruited from the respiratory medicine unit of Nippon Medical School Hospital in Tokyo, Japan. Two individual observers conducted data analysis blinded to patient information.</td>
<td>Interstitial pneumonia</td>
<td>Microphones and Transducer</td>
<td>Fourier Transform</td>
<td>Fine crackles</td>
</tr>
<tr>
<td>Riella et al. (2009)</td>
<td>Curitiba, PR, Brazil</td>
<td>NA</td>
<td>0 - 76</td>
<td>N/A</td>
<td>Lung sound recordings were selected from internet repositories for validation of methodology.</td>
<td>NA</td>
<td>Contact accelerometers</td>
<td>Short-time Fourier Transform, Neural Network</td>
<td>Wheeze</td>
</tr>
</tbody>
</table>
## Table 2

Quality Assessment Score for Selected Studies Based on the Newcastle-Ottawa Quality Assessment Scale by Review

<table>
<thead>
<tr>
<th>STUDY</th>
<th>SELECTION</th>
<th>COMPARABILITY</th>
<th>EXPOSURE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[Average Score]</td>
<td>Adequate Case Definition</td>
<td>Representativeness of the cases</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AG</td>
<td>CGS</td>
</tr>
<tr>
<td>Rietveld 1999 [4]</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
</tr>
<tr>
<td>Murphy 2000 [7.5]</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
</tr>
<tr>
<td>Mor 2007 [7.5]</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
</tr>
<tr>
<td>Kahya 2008 [4]</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
</tr>
<tr>
<td>Gunupalli 2008 [4.5]</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
</tr>
<tr>
<td>Ono 2009 [6.5]</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
</tr>
<tr>
<td>Rieolla 2009 [0]</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
<td>★ ★ ★ ★ ★ ★</td>
</tr>
</tbody>
</table>
Table 3

Summary of Data Available from Studies Included in Meta-analysis

<table>
<thead>
<tr>
<th>STUDY</th>
<th>CONTINGENCY TABLE</th>
<th>TP</th>
<th>FP</th>
<th>FN</th>
<th>TN</th>
<th>SAMPLE SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TP</td>
<td>FP</td>
<td>TP %</td>
<td>FP %</td>
<td>FN %</td>
<td>TN %</td>
</tr>
<tr>
<td>Murphy et al.</td>
<td>39</td>
<td>6</td>
<td>39 %</td>
<td>6 %</td>
<td>11 %</td>
<td>44 %</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mor et al.</td>
<td>14</td>
<td>8</td>
<td>23.3 %</td>
<td>13.3 %</td>
<td>10 %</td>
<td>53.3 %</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kahya et al. Expiratory</td>
<td>18</td>
<td>1</td>
<td>45 %</td>
<td>2.5 %</td>
<td>5 %</td>
<td>47.5 %</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kahya et al. Inspiratory</td>
<td>19</td>
<td>2</td>
<td>47.5 %</td>
<td>5 %</td>
<td>2.5 %</td>
<td>45 %</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ono et al.</td>
<td>17</td>
<td>2</td>
<td>54.8 %</td>
<td>6.4 %</td>
<td>12.9 %</td>
<td>25.8 %</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TP = True Positives
FP = False Positives
FN = False Negatives
TN = True Negatives

*Classification based on data from Observer B.
Utility of an Advanced Digital Electronic Stethoscope in the Diagnosis of Coronary Artery Disease Compared With Coronary Computed Tomographic Angiography

Amgad N. Makaryus, MD, John N. Makaryus, MD, Alan Figgatt, BS, Dan Mulholland, BS, Harvey Kushner, PhD, John L. Semmlow, PhD, Jennifer Mieres, MD, and Allen J. Taylor, MD

The detection of coronary artery microbruits, subaudible bruits too faint to be heard through standard auscultation, may provide an alternative means to diagnose coronary artery disease (CAD). The aim of this study was to test the accuracy of a novel digital electronic stethoscope, the Cardiac Sonospectrographic Analyzer (CSA; SonoMedica model 3.0, SonoMedica, Inc., Vienna, Virginia, United States Food and Drug Administration 510(k) cleared) to diagnose CAD compared to gold-standard diagnosis using cardiac computed tomographic (CT) angiography. In this blinded, single-site study, adults previously referred for CT imaging were selected. Patients underwent CT and CSA evaluations. CSA exams entailed recording heart sounds at 9 positions on the chest for 40 seconds at each position. An algorithm then processed these data to generate a microbruit score. The CT scans were read blinded to patients’ microbruit scores. Sensitivity and specificity of the CSA in detecting CAD compared to CT imaging were estimated using standard receiver-operating characteristic curves calculated from logistic regression models. A total of 161 patients, aged 57 ± 13 years (range 22 to 85), 53% with hypertension and 40% with obesity (body mass index ≥30 kg/m²), completed the protocol and had evaluable CT and CSA examinations. The overall sensitivity of the CSA to identify >50% stenosis in any major epicardial coronary artery as determined by CT imaging was 89.5% (p < 0.0001). Gender-specific models based on smaller sample sizes had slightly poorer results and lower specificity among men with heavy chest hair. In conclusion, the CSA showed high sensitivity and specificity for the detection of significant early CAD in an outpatient setting and represents a new noninvasive device for detecting abnormal coronary blood flow as occurs in CAD.

Acoustical cardiography is a technique that uses heart sound data culled using a specialized stethoscope in concordance with simultaneous digital electrocardiographic data to create an interpretation of the acoustic data. Modeling studies indicate that bruits are generated by arterial wall motion driven by the turbulence in blood flow created by arterial narrowing. By interpreting differences in sound quality produced by laminar flow in an artery not affected by atherosclerotic plaque compared to the turbulent flow produced by some degree of intracoronary obstruction, acoustic cardiography may be able to detect coronary artery disease (CAD) at an early stage. This simple, noninvasive technique has been under various stages of development since the 1980s. Although the traditional stethoscope has long been the physician’s trusted companion in the diagnostic armamentarium, the technological advances wrought by the digital age have allowed significant improvements in the capability to detect CAD using surface auscultation. We sought to assess the diagnostic utility of the Cardiac Sonospectrographic Analyzer (CSA; SonoMedica model 3.0, SonoMedica, Inc., Vienna, Virginia) in predicting and/or ruling out CAD in patients who undergo multidetector computed tomographic (CT) coronary angiography.

Methods

A prospective, single-site evaluation was performed in consecutively selected adults referred for coronary CT angiography as part of their routine medical care. The study was conducted under the auspices of the Institutional Ethics Committee/Human Research Ethics Committee at North Shore University Hospital (Manhasset, New York), and consent was obtained from all patients before their participation. SonoMedica financially supported the study with respect to performance of the sonospectroscopic analysis. Patients were not compensated for their participation in the study. Spectroscopic data were collected by the investigators and analyzed by a core laboratory specializing in sonospectrographic analysis, under the direction of Dr. John Semmlow, professor of biomedical engineering at Robert

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E-mail address: amakaryu@numc.edu (A.N. Makaryus).
Wood Johnson Medical School and Rutgers University. The core laboratory was also responsible for independently verifying the microbruit score (MBS) for each patient. CT data were analyzed blinded to the spectroscopic data at North Shore University Hospital, and results were compared relating to prediction of CAD by the CSA. Statistical analysis was performed by an independent biostatistical research center (Biomedical Computer Research Institute, Philadelphia, Pennsylvania).

Patients eligible for study participation were without known CAD, in good health, and aged ≥21 years. Exclusion criteria included known atherosclerotic heart disease, including a history of myocardial infarction, percutaneous coronary intervention, coronary artery bypass graft surgery, or an established diagnosis of CAD by previous traditional invasive or CT angiography; supraventricular or ventricular arrhythmias that would be expected to affect CT angiographic image quality; previous use of intravenous vasodilators that may affect blood flow hemodynamics; any pulmonary conditions that would create abnormal physical findings that would interfere with the fidelity of the cardiac sound recording; the presence of audible aortic or pulmonary diastolic murmurs, tricuspid or mitral flow diastolic murmurs, or continuous murmurs; and any contraindications to coronary CT angiography.

All patients provided written informed consent. There were 2 phases to the study. The first phase included 25 patients and served only as the initial pilot feasibility study to train study staff members on proper acoustic data collection. This data was not combined with the phase 2 data (n = 200), which served as the definitive study data. A flowchart explaining the patient selection algorithm is provided in Figure 1. Each patient provided a brief medical history through an interview with study personnel. This information included questions on cardiovascular disease, risk factors, anthropometrics, and medications. Vital signs were also taken before CT angiography. The amount of male chest hair, female breast size, and the existence of heart murmurs were also obtained. The medical history and other data were captured on a standardized case report form.

CSA evaluations were performed on each patient. The CSA is a noninvasive digital electronic stethoscope, with United States Food and Drug Administration 510(k) clearance, designed to identify microbruits in the frequency range of 400 to 2,700 Hz, characteristic of abnormal blood flow in atherosclerotic arteries. Microbruits are caused by the same mechanism as auditory bruits, namely, arterial narrowing that produces turbulent blood flow, but they are too faint to be detected by auscultation. The patient was seated in an examination chair, and 4 electrocardiographic leads were attached to the patient’s extremities. An independent reference acoustic sensor was then placed on a table adjacent to the patient to monitor environmental noise. The CSA exam was then performed by sequentially placing the transducer over 9 positions on the chest (Figure 2) and recording heart sounds for 40 seconds at each position. An elastic strap was used to hold the transducer in place at the specified locations on the patient’s chest. The typical CSA recording process, including equipment setup, took approximately 15 minutes, with the acoustic and electrocardiographic signals digitally recorded on a portable computer. The CSA software algorithm processed the recorded data, using the simultaneously recorded electrocardiographic signal to identify the patient’s heartbeat cycle and analyze the acoustic signals to generate the MBS.

The CSA evaluation was conducted before CT angiography and associated β blockade. The CSA evaluation was conducted in the CT preparation area, which was selected to minimize environmental noise; however, the area was at times subject to various levels of uncontrolled environmental noise (intercom announcements, hospital maintenance noise, etc.). All assessments for an individual patient were performed at the same session by trained study personnel. Data collected were compiled and uploaded electronically to the cardiac sonospectrographic core laboratory.

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Figure 1. Patient selection algorithm.
All patients were scanned using a CT scanner (GE Light-Speed VCT; GE Healthcare, Waukesha, Wisconsin) equipped with 64-slice CT technology. Scan parameters included 64 slices per rotation, individual detector slice width of 0.625 mm, and 12.5-cm spatial coverage in 5 seconds at a gantry rotation speed of 330 ms. After the patient was advanced into the scanner bore, a 20-ml test bolus of contrast was administered. Patients were asked to breathe deeply and then hold their breath. After bolus administration of 70 ml of nonionic iodinated contrast material (Omnipaque [iohexol]; GE Healthcare, Amersham Health, Princeton, New Jersey) at a flow rate of 5 ml/s, image acquisition was performed. The scan time was approximately 10 seconds (1 breath hold), and heart rates were titrated using β-blocker therapy to near 60 beats/min. Image acquisition was performed at 10% increments through the R-R cardiac cycle interval. After image acquisition, images were transferred to a GE AW workstation (GE Healthcare), where they were reconstructed with electrocardiographic gating and interpreted by an experienced reader for the presence of CAD as part of the patient’s evaluation in the clinical setting. All patients had valid clinical indications for being referred for cardiac CT imaging.

The coronary CT angiograms were interpreted blinded to patients’ MBS. The CT angiography scan evaluation yielded 17 scores, each measured on a 5-point, Likert-type scale (0 = normal with no calcium, 1 = calcification with no significant narrowing, 2 = minimal/some narrowing [<30%], 3 = mild or mild to moderate narrowing [30% to 50%], 4 = moderate narrowing [>50% to 70%], 5 = severe/significant narrowing [>70%]). The a priori primary CAD end point was the dichotomous CAD outcome of ≤50% narrowing for up to 17 coronary artery locations (CAD negative) versus >50% narrowing in any 1 artery location (CAD positive). A total CAD score equal to the total sum of all locations of the CT imaging–reported CAD levels on the 0-to-5 scale was computed. A peak CAD score was also computed. These were considered secondary CAD end points.

The evaluation of the CSA data was conducted by the acoustic core laboratory, which was blinded to the CT angiographic results. The acoustic core laboratory was responsible for running the acoustic data through the SonoMedica acoustic analysis software to determine the total MBS for each patient. The total MBS formula is based on the statistical approach of taking a geometric mean of the 9 separate and independent MBS recorded from the 9 coronary artery locations (Figure 2). This total MBS has a range of 0 to 1, with 0 representing low probability of clinically significant disease (no disease) and 1 representing high probability of clinically significant disease (severe or significant disease). The total MBS was the a priori primary CSA end point. Each of the 9 MBS was considered a secondary CSA end point.

An a priori statistical analysis plan was developed. The per protocol population was all subjects in the second phase with completed medical histories, physical examinations, and CT and CSA examinations that could be interpreted, and all analyses reported here are based on the per protocol population. Patients with unevaluable CT or CSA examinations were excluded from the per protocol population. Patients were included or excluded on the basis of the quality of their CT and/or CSA evaluations. Such determination was made either by the principal investigator or the acoustic core laboratory, respectively. CT data that were deemed “limited” were excluded if it was agreed that such data could not be used to make a clinical determination of disease. CSA acoustic data were processed using an acoustic assessment algorithm, independently developed by the acoustic core laboratory, which identifies excessive levels of environmental noise. All CSA data that did not meet the noise thresholds were excluded from analysis. In total, 39 patients were excluded from the final analysis set because of (1) no CT data taken (n = 5), (2) limited CT angiographic quality (n = 4), (3) excessive environmental noise in the CSA data (n = 17), (4) a damaged CSA sensor (n = 12), or

![Figure 2. CAD location and sensor placement. LAD = left anterior descending coronary artery.](image-url)
failure to meet the study exclusion criteria (n = 1). An example case is provided in Figure 3.

All numerically continuous data are expressed as mean ± SD unless otherwise stated. Proportions for demographic characteristics were compared using Fisher’s exact test. Sensitivity and specificity of the CSA were estimated using standard receiver-operating characteristic (ROC) curves calculated from logistic regression models. C-statistics (areas under the ROC curves) and p values were also computed. No Bonferroni adjustments were performed for simultaneous multiple comparisons. A p value ≤0.05 was considered statistically significant. All analyses were performed using SAS version 9.2 (SAS Institute Inc., Cary, North Carolina).

Results

A total of 161 of the 200 phase 2 patients (80%), aged 57 ± 13 years (range 22 to 85), 53% with hypertension and 40% with obesity (body mass index ≥30 kg/m²), completed

Multiple Lesions:
1. Prox RCA < 30% stenosis
2. Mid RCA ~ 70% stenosis
3. Prox LAD 30-50% stenosis
4. Mid LAD 30-50% stenosis
5. Prox LCX 50-70% stenosis
6. Mid LCX 50-70% stenosis

Figure 3. Correlation between CSA output and cardiac CT angiographic results. The patient was a 53-year-old man with dyslipidemia and a family history of early coronary disease. LAD = left anterior descending coronary artery; LCx = left circumflex coronary artery; LMCA = left main coronary artery; RCA = right coronary artery.
Table 1
Baseline patient characteristics (primary analysis cohort)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (n = 161)</th>
<th>CAD Narrowing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤50% (n = 142)</td>
<td>&gt;50% (n = 19)</td>
</tr>
<tr>
<td>Men</td>
<td>97 (60%)</td>
<td>83 (58%)</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>57 ± 13 (22–85)</td>
<td>56 ± 13 (22–85)</td>
</tr>
<tr>
<td>Age &gt;60 yrs</td>
<td>75 (47%)</td>
<td>62 (44%)</td>
</tr>
<tr>
<td>Body mass index (m/kg²)</td>
<td>29.7 ± 6.6 (18.5–56.7)</td>
<td>29.9 ± 6.8 (18.5–56.7)</td>
</tr>
<tr>
<td>Body mass index &gt;30 m/kg²</td>
<td>65 (40%)</td>
<td>59 (42%)</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>129 ± 14 (90–160)</td>
<td>129 ± 14 (90–159)</td>
</tr>
<tr>
<td>Diastolic blood pressure (mm Hg)</td>
<td>74 ± 11 (41–108)</td>
<td>74 ± 11 (41–108)</td>
</tr>
<tr>
<td>Moderate to heavy chest hair in men</td>
<td>86/97 (89%)</td>
<td>72/83 (87%)</td>
</tr>
<tr>
<td>History of hypertension</td>
<td>84 (52%)</td>
<td>74 (52%)</td>
</tr>
<tr>
<td>History of dyslipidemia</td>
<td>72 (45%)</td>
<td>63 (45%)</td>
</tr>
<tr>
<td>Preordial murmur</td>
<td>9 (6%)</td>
<td>8 (6%)</td>
</tr>
</tbody>
</table>

Data are expressed as mean ± (range) or as number (percentage).

Table 2
Computed tomographic angiographic characteristics (primary analysis cohort)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (n = 161)</th>
<th>CAD Narrowing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤50% (n = 142)</td>
<td>&gt;50% (n = 19)</td>
</tr>
<tr>
<td>CT angiographic quality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>86 (53%)</td>
<td>75 (53%)</td>
</tr>
<tr>
<td>Fair</td>
<td>58 (36%)</td>
<td>52 (37%)</td>
</tr>
<tr>
<td>Limited</td>
<td>17 (11%)</td>
<td>15 (11%)</td>
</tr>
<tr>
<td>Dominant coronary artery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>149 (93%)</td>
<td>131 (93%)</td>
</tr>
<tr>
<td>Left circumflex</td>
<td>10 (6%)</td>
<td>10 (7%)</td>
</tr>
<tr>
<td>Codominant</td>
<td>1 (&lt;1%)</td>
<td>0</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
<td>64.6 ± 9.1 (26–86)</td>
<td>64.5 ± 8.9 (26–86)</td>
</tr>
<tr>
<td>Total calcium score (Agatston units)</td>
<td>266 ± 616 (0–4405)</td>
<td>212 ± 576 (0–4405)</td>
</tr>
</tbody>
</table>

Data are expressed as number (percentage) or as mean ± (range).

Table 3
Peak coronary artery disease across 4 major arteries

<table>
<thead>
<tr>
<th>Variable</th>
<th>Total (n = 161)</th>
<th>Men (n = 97)</th>
<th>Women (n = 64)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean, no calcium score</td>
<td>44 (27%)</td>
<td>20 (21%)</td>
<td>24 (38%)</td>
</tr>
<tr>
<td>Calcification with no significant narrowing</td>
<td>17 (11%)</td>
<td>8 (8%)</td>
<td>9 (14%)</td>
</tr>
<tr>
<td>Minimal (&lt;30%) or some narrowing</td>
<td>24 (15%)</td>
<td>16 (17%)</td>
<td>8 (12%)</td>
</tr>
<tr>
<td>Mild or mild to moderate narrowing (30% to 50%)</td>
<td>57 (35%)</td>
<td>39 (40%)</td>
<td>18 (28%)</td>
</tr>
<tr>
<td>Moderate narrowing (&gt;50% to 70%)</td>
<td>14 (9%)</td>
<td>10 (10%)</td>
<td>4 (6%)</td>
</tr>
<tr>
<td>Severe or significant narrowing (&gt;70%)</td>
<td>5 (3%)</td>
<td>4 (4%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>≥30% narrowing</td>
<td>76 (47%)</td>
<td>53 (55%)</td>
<td>23 (36%)</td>
</tr>
<tr>
<td>&gt;50% narrowing</td>
<td>19 (12%)</td>
<td>14 (14%)</td>
<td>5 (8%)</td>
</tr>
</tbody>
</table>

Table 3 includes CAD Narrowing levels for all subjects and also by gender. There were 19 subjects (12%) with peak CAD >50% narrowing in any 1 artery (CAD positive). More men than women (14% vs 8%) were classified as CAD positive, but this difference was not statistically significant (p = 0.22). There was no statistically significant correlation between calcium score and total CSA score. The a priori defined primary CAD end point from the CT angiographic evaluation was the peak CAD dichotomous outcome of ≤50% narrowing for up to 17 coronary artery locations (CAD negative) versus >50% narrowing in any 1 artery location (CAD positive). The distribution of the peak CAD is listed in Table 3 for all subjects and also by gender. The protocol and had evaluable CT and CSA examinations (the per protocol population). Demographic and anthropometric data as well as vital signs and medical history data are listed in Table 1 for the entire per protocol population and the CAD-negative and CAD-positive cohorts. Nearly half the population were aged >60 years, obese, and had medical histories of hypertension and hypercholesterolemia. Baseline characteristics were evenly matched. More than half of the CT angiograms were rated as good quality (Table 2), and the dominant artery was the right coronary artery in 93% of the patients.

The a priori defined primary CAD end point from the CT angiographic evaluation was the peak CAD dichotomous outcome of ≤50% narrowing for up to 17 coronary artery locations (CAD negative) versus >50% narrowing in any 1 artery location (CAD positive). The distribution of the peak CAD is listed in Table 3 for all subjects and also by gender. There were 19 subjects (12%) with peak CAD >50% narrowing in any 1 artery (CAD positive). More men than women (14% vs 8%) were classified as CAD positive, but this difference was not statistically significant (p = 0.22). There was no statistically significant correlation between calcium score and total CSA score. (Pearson’s r = 0.09, p = 0.30). The total CSA score was significantly (r = 0.35, p <0.0001) correlated with the number of arteries with peak CAD scores >0 (so as expected, a CAD level >0 indicates some degree of occlusion) and for 8 of the 9 positions of the CSA, the individual position score was significantly correlated with the number of arteries with peak CAD scores >0, demonstrating the individual position sensitivity for CAD.
To determine the sensitivity and specificity of the CSA to predict a CAD-positive outcome, we used logistic regression and computed the ROC curve (Table 4, Figure 4) The overall sensitivity and specificity of 89.5% and 57.7%, respectively, for the CSA to accurately predict CAD were highly statistically significant (p = 0.0007). Gender-specific independent models and ROC curves were also generated. For men (n = 97), the sensitivity and specificity were 85.7% and 50.6%, respectively, which were also statistically significant (p = 0.008, C-statistic = 0.73), and for women, the sensitivity and specificity were 80.0% and 76.3%, but these were not statistically significant (p = 0.10, C-statistic = 0.73), primarily because of the small number of women with disease. With respect to traditional cardiac risk factors and CSA score, we found a significantly greater proportion of patients aged >60 years (p = 0.04) with CSA scores above the cutoff. We found no association with the presence of hypertension, dyslipidemia, or obesity.

Discussion

In our study, we used the CSA to assess the capability of this relatively quick auscultatory exam to detect or rule out CAD. We used multidetector cardiac CT imaging to noninvasively assess for the presence of intraluminal CAD in a real-world patient cohort referred for CT imaging for a multitude of clinical indications, including equivocal myocardial perfusion stress test results, abnormal electrocardiographic findings, and typical cardiac symptomatology, such as chest pain. In meta-analyses comparing multidetector CT imaging with invasive angiography, which remains the gold standard for the assessment of CAD, the sensitivity of multidetector CT imaging was approximately 96% and the specificity 86% for detecting CAD. Despite the heterogeneity of the patient population and the indications for the test, the SonoMedica stethoscope with CSA reliably predicted the presence of CAD in most patients. The overall sensitivity of 89.5% and specificity of 57.7% for the CSA to predict CAD were statistically significant (p = 0.0007).

This finding is very pertinent in the current age of increasing expenditures for imaging modalities to assess for the presence of CAD. From 1960 to 2006, the United States has experienced an average of 4.8% per year growth in health expenditures. A big chunk of this is related to cardiac imaging. In 2006, the payment to cardiologists for imaging services by Medicare represented 8.7% of total payments for all physician services. Factoring estimates of payments by private health insurance, the total expenditures related to cardiovascular imaging are estimated to approach $17 billion. To address this growing issue, many organizations have cut payment for cardiac imaging studies, decreased approvals for these studies, and convened working groups to assess appropriate-use recommendations to curtail costs. The one avenue that has not been adequately explored or looked at is using more cost efficient imaging tools to better stratify and diagnose the presence or absence of CAD or even be used as a first step to prioritize patients who may be recommended to go on to further imaging on the basis of the findings.

Exercise electrocardiography is being implemented at many chest pain centers and is being used as the “gatekeeper” for the decision algorithm in patients presenting with chest pain. On the basis of our findings in the present study, the SonoMedica CSA is an ideal tool that can serve either as a stand-alone or complementary technique in the analysis of patients being evaluated for CAD. This relatively robust technique assesses an anatomic finding of plaque presence using assessment of microbruits. Application of this relatively cost effective (compared to cardiac imaging modalities) and efficient technique can help clinicians risk-stratify patients and make appropriate clinical decisions for management and potentially guide future therapy.

Disclosures

Alan Figgatt and Dan Mulholland holds shares in Sonomedica and is a paid software consultant to the company. Dr. John Semmlow holds shares in Sonomedica and is a member of the company’s Medical Advisory Board. Dr. Harvey Kushner holds no shares or options, paid statistical consultant (through Sonomedica) for this study. The remaining authors have no conflicts of interest to disclose.


5. Gorenoi V, Schönemark MP, Hagen A. CT coronary angiography vs. invasive coronary angiography in CHD. *GMS Health Technol Assess* 2012;8:Doc02.


Abstract

An electronic stethoscope is disclosed having a palm sized electronic component case with operating switches provided on opposite sides of the case for ease of operation. The stethoscope includes a pickup head coupled to an electronic microphone by means of a flexible tubular acoustic member. A battery powered amplifier and filter circuit is provided within the component case and the amplified and filtered output of the microphone is coupled to a miniature speaker sealed within an airtight container within the case. A rotatable tubular member having radial apertures therein is coupled through the sealed container and out each side of the component case. A binaural headpiece is acoustically coupled to each end of the rotatable member and is thus free to rotate with respect to the case, allowing the stethoscope to fold for storage. In a preferred embodiment of the present invention, electronic timing means are provided for automatically removing electrical power from than amplifier circuit after a predetermined period of time and for generating an audible tone at preselected intervals for pulse rate measurement.

8 Claims, 3 Drawing Figures
1

ELECTRONIC STETHOSCOPE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Ser. No. 480,062, filed Mar. 29, 1983.

BACKGROUND OF THE INVENTION

This invention relates to stethoscopes in general and in particular to stethoscopes including electronic amplification circuitry. Still more particularly, this invention relates to improved electronic stethoscopes having enhanced noise rejection characteristics and automatic power conservation circuitry and which are designed to resemble simple acoustic stethoscopes in size and convenience.

Both electronic and acoustic stethoscopes and combinations of these two are well known in the art. One example of an electronic stethoscope is described in U.S. Pat. No. 3,247,324. That stethoscope includes a pickup head which is acoustically coupled to a microphone. The signals picked up by that microphone are then amplified and provided to a speaker which is acoustically coupled to a conventional binaural headpiece by means of flexible conduits. The stethoscope disclosed in U.S. Pat. No. 3,247,324 also permits direct acoustical connection between the pickup head and the binaural headpiece.

Electronic stethoscopes known in the prior art have not been generally accepted by medical practitioners due to several problems which exist in those designs. Typically, these known devices have been bulky and difficult to utilize, carry or store. Further, known electronic stethoscopes have suffered from reliability problems due to battery problems and interference due to background high frequency interference from fluorescent light fixtures or other sources. Clearly, there has existed a need for an electronic stethoscope which is physically similar to acoustic stethoscopes in size and convenience and which is not subject to the vagaries of known circuitry.

SUMMARY OF THE INVENTION

It is therefore one object of the present invention to provide an improved electronic stethoscope.

It is another object of the present invention to provide an improved electronic stethoscope which folds and stores in the manner of an acoustic stethoscope.

It is yet another object of the present invention to provide an improved electronic stethoscope which includes filter circuitry for enhancing selected frequency bands.

It is another object of the present invention to provide an improved electronic stethoscope which includes circuitry of automatically removing electrical power from the device after a selected period of time has elapsed to prevent excessive battery drain.

It is yet another object of the present invention to provide an improved electronic stethoscope which includes circuitry for generating periodic audible pulses or tones for utilization in pulse rate measurements.

The foregoing objects are achieved as is now described. The electronic stethoscope of the present invention includes a palm sized electronic component case with operating switches provided on opposite sides of the case for ease of operation. The stethoscope includes a pickup head coupled to an electronic microphone by means of a flexible tubular acoustic member. A battery powered amplifier and filter circuit is provided within the component case and the amplified and filtered output of the microphone is coupled to a miniature speaker sealed within an airtight container within the case. A rotatable tubular member having radial apertures therein is coupled through the sealed container and out each side of the component case. A binaural headpiece is acoustically coupled to each end of the rotatable member and is thus free to rotate with respect to the case, allowing the stethoscope to fold for storage. In a preferred embodiment of the present invention, electronic timing means are provided for automatically removing electrical power from the amplifier circuit after a predetermined period of time and for generating an audible tone at preselected intervals for pulse rate measurement.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself; however, as well as a preferred mode of use, further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a perspective view of the novel electronic stethoscope of the present invention;

FIG. 2 is a sectional view of the novel rotatable acoustic coupling section of the electronic stethoscope of the present invention; and

FIG. 3 is a schematic diagram of the electronic circuitry of the electronic stethoscope of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the figures and in particular with reference to FIG. 1, there is depicted a perspective view of electronic stethoscope 10 of the present invention. As can be seen, stethoscope 10 includes a standard acoustic pickup head 12 which is coupled to an electronic component case 14 by means of a flexible tubular acoustic member 16. Electronic component case 14 is preferably constructed of plastic material such as polyethylene and includes an "on" switch 18, an "off" switch 20, and a slidable volume switch 22 which is disposed on the opposite side of electronic component case 14 from switches 18 and 20. Further, electronic component case 14 is preferably palm sized, or approximately three inches in width so that an individual may operate switches 18 and 20 with his fingertips while simultaneously adjusting volume switch 22 with his thumb. This particular switch configuration and case size are important features of electronic stethoscope 10 and contribute greatly to the ease of operation of this device.

Depicted within electronic component case 14 is rotatable acoustic coupling section 24 which serves to mount speaker 26 in a manner which will be explained in detail below. The output of acoustic coupling section 24 is rotatably coupled to binaural headpiece 28 utilizing flexible tubes 32. This rotatable coupling of binaural headpiece 28 is an important feature of electronic stethoscope 10 and permits electronic stethoscope to be folded and stored in the same manner as an acoustic stethoscope, as depicted in phantom lines within FIG. 1.
Binaural headpiece 28 also includes silicon rubber earpieces 30 which will maximize wearer comfort during use of electronic stethoscope 10.

Referring now to FIG. 2, there is depicted a sectional view of rotatable acoustic coupling section 24 of electronic stethoscope 10. As can be seen in FIGS. 1 and 2, acoustic coupling section 24 comprises a rectangular sealed container which is preferably airtight and which is also constructed of plastic materials similar to electronic component case 14. An aperture in the upper surface of acoustic coupling section 24 is utilized to receive and sealably mount speaker 26. Speaker 26 is preferably a high efficiency acoustic speaker, the output of which is directed into the interior of acoustic coupling section 24. Thus, any acoustic signals coupled to speaker 26 will be audibly generated within the confines of acoustic coupling section 24.

Mounted through acoustic coupling section 24 and extending out through each side of electronic component case 14 is a rotatable tubular member 34 which serves to couple the acoustic signals within acoustic coupling section 24 out to binaural headpiece 28 by means of flexible tubes 32. In a preferred embodiment of the present invention, rotatable tubular member 34 is a metallic cylinder which includes axial bores 36 and 38 which extend into the interior of acoustic coupling section 24. Additionally, flanges 40 and 42 are provided to seal the point at which rotatable tubular member 34 penetrates acoustic coupling section 24. Those ordinarily skilled in the art will appreciate that o-rings or other sealing means may also be utilized to provide sealing at the point of penetration with acoustic coupling section 24.

As can be seen in FIG. 2, axial bores 36 and 38 are penetrated by radial apertures 44 and 46 in the vicinity of speaker 26 and thus permit the acoustic signals within acoustic coupling section 24 to enter axial bores 36 and 38 and be acoustically coupled out of acoustic coupling section 24 through axial bores 36 and 38 and into flexible tubes 32. Radial apertures 44 and 46 represent an important feature of the acoustic coupling section of electronic stethoscope 10 and are preferably situated at an angle which maximizes acoustic coupling from speaker 26 when binaural headpiece 28 rotated into the position depicted in FIG. 1, for utilization of electronic stethoscope 10 in a practical manner.

With reference now to FIG. 3, there is depicted a schematic diagram of the electronic circuitry of electronic stethoscope of the present invention. Where possible, the reference numerals utilized in FIGS. 1 and 2 have been utilized to identify the same components depicted in schematic form in FIG. 3. As can be seen, flexible tubular acoustic member 16 couples pickup head 12 (not shown) to electronic microphone 50 via a push fit connector 52. The output of microphone 50 is then coupled via resistors 54 and 56 and capacitor 58 to potentiometer 22.

The signal applied to potentiometer 22, minus high frequencies filtered out by capacitors 60 and 62, is then coupled to the input of amplifier 64 for amplification and filtering by means of capacitors 66 and 68 in a feedback loop. Final filtering is accomplished by capacitors 70 and 72 and the effect of the filter network is to enhance the frequency band between twenty and seven hundred hertz before applying the amplified and filtered output of microphone 50 to speaker 26 within acoustic coupling section 24. In this manner any spurious high frequency transmissions originating in fluorescent fixtures or the like will be filtered out of the resultant signal.

Electrical power is applied to amplifier 64 by means of a gate controlled conduction device 76, a PNP transistor, which is coupled between battery 78 and pin 6 of amplifier 64. The bias present on the base of transistor 76, and thus the conduction of electrical power to amplifier 64, is controlled by timing and control circuit 80.

In a preferred embodiment of the present invention, timing and control circuit 80 is implemented utilizing a quad two-input NAND gate integrated circuit device such as the CD4093 manufactured by National Semiconductor of Santa Clara, Calif. Timing and control circuit 80 is utilized for four separate timing or control outputs in a highly efficient and novel manner. One function of timing and control circuit 80 is to provide an automatic removal of electrical power from amplifier 64 after the elapse of a selected period of time. Power is applied to amplifier 64 by a momentary depression of "on" switch 18 which causes capacitor 82 to charge to battery potential. The voltage present on capacitor 82 is then coupled to pin 1 of timing and control circuit 80 and together with the battery potential at pin 2 will cause an output at pin 3 which will turn on transistor 76.

Automatic power removal is accomplished by allowing capacitor 82 to slowly discharge through resistor 84 until such time as the voltage present drops below the level necessary to provide the desired input at pin 1. At that time, transistor 76 will cease conduction and electrical power will be removed from amplifier 64. In a preferred mode of this invention, this period of time should be between two and three minutes to minimize possible battery drain due to inadvertent failure to depress the "off" switch. Those skilled in this art will appreciate that a manual depression of "off" switch 20 can be utilized to cause a rapid discharge of capacitor 82 through the much smaller resistance of resistor 88.

In a similar manner, switch 90 can be utilized to generate a periodic signal in the audible range at pin 11 of timing and control circuit 80. This audible signal or tone is coupled to pin 8 of amplifier 64 and superimposed on the output thereof to provide a calibrated timing tone for pulse rate measurements. The resistive and capacitive elements coupled to pins 8, 12, 10, 13 and 11 of timing and control circuit 80 are utilized, in a manner well known in the art, to select the frequency of the timing tone, the duration of that tone and the duration between consecutive tones. Preferably, a short tone is sounded every fifteen seconds when switch 90 is closed to enable a simple pulse rate calibration for pulse beats per minute.

As can be seen, the electronic circuitry of FIG. 3 is a highly efficient utilization with a minimum amount of electronic components and can be easily mounted on a printed circuit board within electronic component case 14.

Although the invention has been described with reference to a specific embodiment, this description is not meant to be construed in a limiting sense. Various modifications of the disclosed embodiment as well as alternative embodiments of the invention will become apparent to persons skilled in the art upon reference to the description of the invention. It is therefore contemplated that the appended claims will cover any such modifications or embodiments that fall within the true scope of the invention.

What is claimed is:

1. An electronic stethoscope comprising:
an electronic component case for encompassing electronic components in circuitry;
a pickup head;
a microphone;
a first tubular acoustic member coupling said pickup head and said microphone;
a binaural headpiece;
a speaker mounted within said electronic component case;
an amplifier circuit having its input coupled to said microphone and its output coupled to said speaker;
a rotatable tubular member disposed adjacent to said speaker and extending out through each side of said electronic component case for coupling the output of said speaker out of said electronic component case; and
means coupling said binaural headpiece to said rotatable tubular member whereby said binaural headpiece may be rotated with respect to said electronic component case for ease in storage of said electronic stethoscope.

2. The electronic stethoscope according to claim 1 further including switch means for applying electrical power to said amplifier circuit in response to operation thereof.

3. The electronic stethoscope according to claim 1 further including timer means for removing electrical power from said amplifier circuit after a predetermined period of time has elapsed.

4. The electronic stethoscope according to claim 1 wherein said rotatable tubular member comprises a hollow metallic cylinder having radial apertures in the body thereof.

5. The electronic stethoscope according to claim 1 wherein said electronic component case is rectangular in shape.

6. An electronic stethoscope according to claim 1 wherein said electronic component case includes a first switch means for applying electric power to said amplifier circuit in response to operation thereof and said second switch means for varying the amplification of said amplifier circuit said first and second switch means disposed on opposing sides of said case whereby said first and second switch means may be operated by the thumb and fingers of an individual grasping said case.

7. The electronic stethoscope according to claim 6 wherein said second switch means comprises a slide switch.

8. The electronic stethoscope according to claim 6 further including a third switch means for removing electrical power from said amplifier circuit in response to operation thereof, said third switch means disposed adjacent to said first switch means for finger control.
ELECTRONIC STETHOSCOPE

Inventors: Jocelyn Durand, Joliette; Louis-Gilles Durand, St-Jean-de-Matha; Marie-Claude Grenien, Montreal, all of Canada

Assignee: Theratechnologies Inc., Montreal, Canada

App. No.: 164,382
Filed: Dec. 9, 1993

Related U.S. Application Data

Int. Cl. 66/1B 7/04
U.S. Cl. 381/67; 381/72; 381/123
Field of Search 381/67, 94, 123, 381/25, 72, 74, 68.4, 104, 107, 108; 128/715

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2,340,714 2/1944 Traver et al .
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ABSTRACT
The electronic stethoscope is designed to minimize the influence of the various types of noise while optimizing auscultation of the sounds of interest, and to enable a cardiologist to auscultate mechanical heart valves. It comprises a probe for sensing sounds of interest produced within a patient's body and for converting these sounds to an electric signal, and an audio amplifier and earphones for reproducing the sounds of interest in response to this electric signal. The stethoscope comprises (a) a first filter unit having a frequency response that optimizes filtering of the tremor and passing of the low frequency sound components of interest in the range including the frequencies lower than 75 Hz, (b) a second filter unit having a frequency response that optimizes both attenuation of the ambient noise and passing of the sound components of interest in the range 110–1300 Hz, taking into consideration the variation of sensitivity of the human ear in function of frequency, (c) a third filter unit for passing the sounds of mechanical heart valves, and (d) a level detector detecting the amplitude level of the electric signal to activate a pulse generator of which the pulses are applied to the audio amplifier for momentarily and repeatedly disabling this audio amplifier when the detected amplitude level is higher than a predetermined amplitude level threshold.

6 Claims, 5 Drawing Sheets
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5,022,405 6/1991 Hok et al .
1 ELECTRONIC STETHESCOPE

This application is a continuation-in-part of application Ser. No. 07/986,596, filed Dec. 7, 1992, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an electronic stethoscope capable of detecting and reproducing sounds of interest while eliminating most of the undesirable noise disturbing the physician or other medical practitioner during auscultation.

2. Brief Description of the Prior Art

A plurality of electronic stethoscopes have been proposed in the past. Examples are described and illustrated in the following United States patents:

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Inventor(s)</th>
<th>Filing Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,247,324</td>
<td>Ceafy et al.</td>
<td>04/19/1996</td>
</tr>
<tr>
<td>4,170,717</td>
<td>Wohlspe</td>
<td>10/09/1979</td>
</tr>
<tr>
<td>4,224,302</td>
<td>Wohlspe</td>
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</tr>
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<td>4,534,058</td>
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<td>08/06/1985</td>
</tr>
<tr>
<td>4,594,731</td>
<td>Lewkowicz</td>
<td>06/10/1986</td>
</tr>
</tbody>
</table>

Although many electronic stethoscopes are available on the market, they have never been widely accepted by the physicians and other medical practitioners. A clinical study in different fields of the medical profession indicates that non-acceptance of the electronic stethoscopes is mainly due to the production of noise (or artefacts) disturbing the physician or other medical practitioner during auscultation as well as to the incapacity of these stethoscopes to amplify and reproduce certain biological sounds of interest. These two considerations are not redundant. Indeed, a biological sound can be either present but covered by noise, or totally absent.

Many sources of noise have been identified. These noise sources usually have a high amplitude and/or a frequency characteristic situated within the frequency range of the signal of interest whereby the quality of auscultation is substantially reduced. Of course, an efficient electronic stethoscope should be capable of processing these different sources of noise.

“Noise” is defined as being any signal other than that of interest, and can be divided into the following four categories:

A. External noise;
B. Noise related to auscultation;
C. Noise generated by the electronic circuits of the stethoscope; and
D. Noise of biological nature produced by the patient’s body.

A. External noise:

This external, ambient noise is not directly connected to auscultation, but originates from the environment of the physician, the patient, and the stethoscope. For example, external noise is produced by the telephone, voice, medical equipment, etc. Its frequency characteristic is situated within the range 300-3000 Hz. These acoustic waves are sensed by the electroacoustic transducer (microphone) of the stethoscope and then amplified and transmitted to the ears of the physician or other medical practitioner.

Although it is attenuated by the stethoscope probe, the external noise is still perceived by the medical practitioner as being dominant since sensitivity of the human ear is higher at ambient noise frequencies. Reference can be made to the Fletcher-Munson curves showing that a sound at a frequency of 1 kHz is perceived up to 100 times louder than a sound of same intensity at a frequency of 100 Hz. Lower sensitivity of the human ear to the low frequencies of the biological sounds results in a weaker perception thereof.

The above mentioned clinical study has determined that, amongst the various types of noise, external noise is the most disturbing. For example, the sound of a normal heart has a frequency characteristic situated within the range of 20-200 Hz and is particularly covered and affected by ambient noise. Measure of blood pressure is particularly affected by external noise since Korotkoff’s sounds have low frequency characteristics.

B. Noise related to auscultation:

The three following sources of noise are associated to auscultation of a patient:

1° Noise related to the preauscultation manipulation;
2° Movements of the physician and/or patient (movements perceptible by human eyes); and
3° Tremor (involuntary trembling motion of the hand of the physician mostly imperceptible by human eyes).

1° Noise related to the preauscultation manipulation:

This category includes impacts between the probe (including the electroacoustic transducer) of the stethoscope and hard objects, and the noise produced upon adjusting the different controls (switches, potentiometers, etc.) of the stethoscope. In particular, when the probe hits an object the resulting sound is sensed by the electroacoustic transducer and is then amplified to produce a very high amplitude transitory signal. Under certain circumstances, the transitory signal can have an amplitude sufficient to harm the ears of the user. Moreover, when the controls (switches, potentiometers, etc.) are mounted close to the electroacoustic transducer, adjustment thereof is susceptible to produce very unpleasant artefacts if they are not adequately isolated from the electroacoustic transducer.

2° Movements of the physician and/or patient (movements perceptible by human eyes):

Upon carrying out auscultation, noise can be generated when the physician or other medical practitioner positions and displaces the probe on the patient’s body. Movement of the patient’s body with respect to the probe produces the same type of noise. In both cases, the generated noise has a relatively high intensity. The power of these artefacts is relatively low, in particular when the probe is positioned and then displaced on the clothes of a patient.

3° Tremor:

Considerable efforts have been made to identify and characterize the sound of a low frequency rumble wrongly associated to background noise. This low frequency rumble is generated by an involuntary trembling motion of the hand of the physician or other medical practitioner during auscultation, twinned with the sensitivity of the electroacoustic pressure transducer of the stethoscope.

When the stethoscope is applied to the patient’s body by a physician or other medical practitioner, a low frequency rumble is produced and superposed to the biological sounds of interest. On the contrary, the low frequency rumble disappears when the probe of the stethoscope is held on the patient’s body by means of an elastic belt instead of the physician’s hand. This low frequency rumble is produced by an involuntary trembling motion (tremor) of the physician’s hand, which trembling motion is mostly imperceptible by human eyes and has muscular origins (positioning feedback). It is interesting to note that the low frequency rumble
considerably reduces in intensity when the probe of the stethoscope is held in the air; the explanation is that an electroacoustic transducer placed in a closed space is more sensitive to variations of pressure in the cavity than to the movement itself. Of course, when the probe of the stethoscope is applied to the patient's body, the involuntary trembling motion of the hand creates variations of pressure in the air compartment between the electroacoustic transducer and the patient's body. The electroacoustic transducer senses these pressure variations and generates in response thereto a low frequency signal of which the frequency characteristic is mainly situated in the range 10–100 Hz. When held in the air, the electroacoustic transducer is subjected almost only to static atmospheric pressure whereby the rumble considerably reduces and can even disappear.

C. The noise generated by the electronic circuits of the stethoscope:
This kind of noise includes harmonic distortion caused by saturation of the electronic circuits and modifying the signal of interest, as well as residual background noise of electronic nature superposed to the signal of interest. Proper design of the electronic circuits enables this noise to be, if not completely eliminated, considerably reduced.

D. The noise of biological nature generated by the patient's body:
As defined in the foregoing description, "noise" is any signal other than that of interest. Therefore, the sounds of biological nature produced by the patient's body can be considered as being noise. Accordingly when a cardiologist auscultates a low frequency sound (for example B3 or B4 heart sounds), muscular trembling, noise generated by the intestinal peristalsis, pulmonary sounds as well as high frequency heart sounds (murmurs, mechanical heart valves, etc.) all constitute noise which disturbs his concentration.

Generally, the prior art electronic stethoscopes have a frequency bandwidth covering the ranges of frequencies of the biological sounds of interest, mentioned in the following TABLE OF COMMON AUSCULTATORY SOUNDS. This well-known table identifies the frequency contents of the cardiac, respiratory and fetal sounds of interest. To those sounds should be added the Korotkoff's arterial sounds auscultated upon measuring blood pressure and mainly situated in the frequency range 20–150 Hz. Accordingly, the prior art stethoscopes designed from the information given in this table present various frequency responses comprised between 20–2000 Hz.

<table>
<thead>
<tr>
<th>TABLE OF COMMON AUSCULTATORY SOUNDS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CARDIAC</strong></td>
</tr>
<tr>
<td>LOW</td>
</tr>
<tr>
<td>20</td>
</tr>
<tr>
<td>15</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>MEDIUM</td>
</tr>
<tr>
<td>400</td>
</tr>
<tr>
<td>HIGH</td>
</tr>
<tr>
<td>660</td>
</tr>
<tr>
<td>140 PERICARDIAL RUB</td>
</tr>
<tr>
<td>660</td>
</tr>
<tr>
<td><strong>RESPIRATORY</strong></td>
</tr>
<tr>
<td>AMPHORIC BREATHING</td>
</tr>
<tr>
<td>240</td>
</tr>
<tr>
<td>660</td>
</tr>
<tr>
<td>BRONCHIAL BREATHING</td>
</tr>
<tr>
<td>240</td>
</tr>
<tr>
<td>1000</td>
</tr>
<tr>
<td>VESICULAR BREATHING</td>
</tr>
<tr>
<td>150</td>
</tr>
<tr>
<td>750 CREPITATION ETC.</td>
</tr>
<tr>
<td>BREATH SOUNDS HEARD IN TRACHEA</td>
</tr>
<tr>
<td>800 1000 1200 1300–1700</td>
</tr>
<tr>
<td>FETAL</td>
</tr>
<tr>
<td>16 FETAL HEART SOUNDS</td>
</tr>
</tbody>
</table>

LOW
- PRESYSTOLIC AND SOME SYSTOLIC MURMURS
- BASAL AND MURAL DIASTOLIC MURMURS
- AURICULAR AND 1st, 2nd & 3rd HEART SOUNDS
- GALLOP RHYTHMS

MEDIUM AND HIGH
- SYSTOLIC AND DIASTOLIC MURMURS
OBJECTS OF THE INVENTION

An object of the present invention is therefore to eliminate the above discussed drawback of the prior art electronic stethoscopes.

Another object of the present invention is to provide an electronic stethoscope capable of minimizing the influence of the various types of noise while optimizing auscultation of the sounds of interest.

A further object of the present invention is to provide an electronic stethoscope enabling a cardiologist to auscultate mechanical heart valves.

SUMMARY OF THE INVENTION

More specifically, in accordance with a first aspect of the present invention, there is provided an electronic stethoscope comprising first means for sensing sounds of interest produced within a patient's body and for converting these sounds to an electric signal, wherein the first means is manipulated by a user's hand, the electric signal includes low frequency noise generated by an involuntary trembling motion of the user's hand upon manipulating the first means, and the noise and sounds both have frequency components situated within a common low frequency range. A filter unit attenuates the electric signal in the common low frequency range, and comprises second means for filtering from the electric signal a substantial part of the noise and components in lower frequencies of that range, and third means for passing a substantial part of the sound components in higher frequencies of the same range. Finally, fourth means reproduces the sounds of interest in response to the electric signal from the filter unit to enable the user to hear and listen to these sounds. In accordance with preferred embodiments, (a) the common low frequency range comprises frequencies lower than 75 Hz, (b) the filter unit produces an attenuation of about 40 dB at a frequency of 30 Hz and an attenuation of about 3 dB at a frequency of 70 Hz, and (c) the filter unit comprises serially interconnected first and second high-pass filters. The first high-pass filter produces an attenuation of about 3 dB at a frequency of 60 Hz and an overshoot of about 3 dB at a frequency of 80 Hz. The second high-pass filter produces an attenuation of about 3 dB at a frequency of 80 Hz.

The present invention also relates to an electronic stethoscope comprising (a) first means for sensing sounds of interest produced within a patient's body and for converting these sounds to an electric signal, wherein the first means are capable of sensing external ambient sounds whereby the electric signal includes noise generated by those external ambient sounds, and wherein the noise and sounds both have frequency components situated within a common frequency range, (b) a filter unit for attenuating the electric signal in the common frequency range, this filter unit having a frequency response adequate to optimize both attenuation of the noise components and passing of the sound components, taking into consideration the variation of sensitivity of the human ear in function of frequency, and (c) second means for reproducing the sounds in response to the electric signal from the filter unit to enable a user to hear and listen to the sounds of interest. According to a first preferred embodiment, the electronic stethoscope can operate in a diaphragm mode and the common frequency range comprises the frequency range situated between 160 and 1300 Hz, and the filter unit comprises a low-pass filter producing an attenuation of about 3 dB at a frequency of 160 Hz and an attenuation of about 40 dB at a frequency of 700 Hz. According to a second preferred embodiment, the electronic stethoscope can operate in a bell mode and the common frequency range comprises the frequency range situated between 110 and 1300 Hz, and the filter unit comprises a low-pass filter producing a gain of about 3 dB at a frequency of 90 Hz, an attenuation of about 3 dB at a frequency of 120 Hz and an attenuation of about 40 dB at a frequency of 550 Hz.

Further in accordance with the present invention, there is provided an electronic stethoscope comprising first means for sensing sounds of interest produced within a patient's body and for converting these sounds of interest to an electric signal, wherein the sounds of interest comprise sounds produced by a mechanical heart valve having frequency components situated within a high frequency range, and second means for reproducing the sounds of interest in response to the electric signal to enable a user to hear and listen to the sounds of interest. A third filter means is interposed between the first and second means for passing the frequency components situated within the high frequency range and included in the electric signal, and a fourth means is responsive to detection of these frequency components for transmitting these components from the third filter means to the second means for reproduction of the sounds of the mechanical heart valve. Preferably, the high frequency range comprises the frequency range situated between 1.3 and 20 kHz, and the third filter means comprises a band-pass filter producing an attenuation of about 40 dB at a frequency of 2.5 kHz, an attenuation of about 20 dB between 5 and 10 kHz, and an attenuation of about 40 dB at a frequency of 30 kHz.

The present invention further relates to an electronic stethoscope comprising first means for sensing sounds of interest produced within a patient's body and for converting these sounds of interest to an electric signal, and second means for reproducing the sounds of interest in response to the electric signal from the first means, given by way of example only with reference to the accompanying drawings.
BRIEF DESCRIPTION OF THE DRAWINGS

In the appended drawings:

FIG. 1 is a schematic block diagram of the preferred embodiment of the electronic stethoscope in accordance with the present invention, comprising an anti-tremor filter unit, an external noise isolating filter unit, a mechanical valve filter unit, and an inner ear protecting unit;

FIG. 2 is a logarithmic graph showing the frequency response of the electronic stethoscope of FIG. 1;

FIG. 3 is a block diagram of the anti-tremor filter unit of the electronic stethoscope of FIG. 1;

FIG. 4 is a block diagram of the external noise isolating filter unit of the stethoscope of FIG. 1;

FIG. 5 is a block diagram of the mechanical valve filter unit of the electronic stethoscope of FIG. 1; and

FIG. 6 is a block diagram of the inner ear protecting unit of the electronic stethoscope of FIG. 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In the different figures of the appended drawings, the corresponding elements are identified by the same reference numbers.

The electronic stethoscope in accordance with the present invention is generally identified by the reference 10 in FIG. 1.

As illustrated in FIG. 1, the stethoscope 10 comprises an electroacoustic transducer (microphone) 12. The electroacoustic transducer 12 obviously forms part of a probe (not shown) of the electronic stethoscope 10, applied to the patient's body during auscultation. The electroacoustic transducer 12 is capable of sensing, when the probe is applied to the patient's body, the sounds of interest produced within the patient's body and of converting these sounds to an electric signal.

The low-level electric signal from the electroacoustic transducer 12 is amplified by a preamplifier 13 before being applied to an anti-tremor filter unit 14. As well known to those of ordinary skill in the art, the preamplifier 13 presents suitable input and output impedances and provides gain so that the low-level signal from the electroacoustic transducer 12 may be further processed without appreciable degradation in the signal-to-noise ratio.

Referring to FIG. 2, the anti-tremor filter unit 14 attenuates the electric signal in the low frequency range including frequencies lower than 75 Hz (section A of the frequency response of FIG. 2). As indicated in the foregoing description, the frequency characteristic of the tremor is mainly situated in the frequency range 10–100 Hz, that frequency range also including low frequency heart sounds (see the above TABLE OF COMMON AUSCULTATORY SOUNDS) and the Korotkoff's sounds. Accordingly, the anti-tremor filter unit 14 should minimize the influence of the tremor while optimizing auscultation of these low frequency sounds of interest. It has been found that a high-pass filter unit adjusted to produce an attenuation of about 40 dB at a frequency of 30 Hz and an attenuation of about 3 dB at 70 Hz appropriately fulfills this dual function (see section A of the frequency response of FIG. 2).

To obtain section A of the frequency response of FIG. 2, the anti-tremor filter unit 14 is formed, as shown in FIG. 3, of two serial high-pass filters 15 and 16. As illustrated, filter 15 produces an attenuation of about 3 dB at a frequency of 60 Hz (point 17 in FIG. 3) and an overshoot of about 3 dB at a frequency of 80 Hz (point 11 in FIG. 3), while filter 16 produces an attenuation of about 3 dB at a frequency of 80 Hz (point 18 of FIG. 3). Superimposition of the frequency responses of the high-pass filters 15 and 16 provides section A of the frequency response of FIG. 2. The key is that such superimposition will cut lower frequency tremor but will not affect drastically higher frequency useful signal. More specifically, filter unit 14 removes from the electric signal a substantial part of the noise components in lower frequencies of the range including frequencies lower than 75 Hz, and passes a substantial part of the sound components of interest in higher frequencies of the same range.

The filtered electric signal from the anti-tremor filter unit 14 is supplied to a volume control 19. Volume control 19 is a circuit allowing the physician to adjust the volume of the sounds reproduced by means of the stethoscope 1. For that purpose, volume control 19 will raise or lower the amplitude of the electric signal from the output of the anti-tremor filter unit 14. Volume control 19 may include an adjustable resistive element (not shown), associated or not with an amplifier (not shown) and manually actuated by the physician while manipulating the stethoscope's probe. Volume controls are well known to those of ordinary skill in the art and accordingly volume control 19 will not be further described in the present disclosure.

The electric signal from volume control 19 is supplied to an external noise isolating filter unit 20 and to a mechanical valve filter unit 21.

As illustrated in FIG. 4, external noise isolating filter unit 20 comprises a diaphragm mode low-pass filter 22 and a bell mode low-pass filter 23.

Low-pass filter 22 allows the stethoscope 10 to operate in the diaphragm mode. It attenuates the electric signal in the frequency range 160–1300 Hz (curve 24 of section B of the frequency response of FIG. 2). As indicated in the foregoing description, the external noise has a frequency characteristic situated in the frequency range 300–3000 Hz. The above TABLE OF COMMON AUSCULTATORY SOUNDS also indicates that medium and high frequency heart and respiratory sounds form part of the frequency range 160–1300 Hz. Therefore, the diaphragm mode low-pass filter 22 should minimize the influence of the external noise while optimizing auscultation of the sounds of interest in the frequency range 160–1300 Hz. It has been found that a low-pass filter 22 adjusted to produce an attenuation of about 3 dB at a frequency of 160 Hz (point 25 of FIG. 4) and an attenuation of about 40 dB at a frequency of 700 Hz (point 26 of FIG. 4) appropriately fulfills this dual function (see curve 24 of section B of the frequency response of FIG. 2) while taking into consideration the above mentioned variation of sensitivity of the human ear in function of frequency. As can be seen in FIG. 2, external noise components having a frequency higher than 1300 Hz are greatly attenuated by the diaphragm mode low-pass filter 22.

Low-pass filter 23 allows the stethoscope 10 to operate in the bell mode. It attenuates the electric signal in the frequency range 110–1300 Hz (curve 27 of section C of the frequency response of FIG. 2). As indicated in the foregoing description, the external noise has a frequency characteristic situated in the frequency range 300–3000 Hz. The above TABLE OF COMMON AUSCULTATORY SOUNDS also indicates that medium and high frequency heart and respiratory sounds form part of the frequency range 110–1300 Hz. Therefore, the bell mode low-pass filter 23 should minimize the influence of the external noise while optimiz-
ing auscultation of the sounds of interest in the frequency range 110–1300 Hz. It has been found that a low-pass filter 23 adjusted to produce a gain of about 3 dB at a frequency of 90 Hz (point 28 of FIG. 4), an attenuation of about 3 dB at 120 Hz (point 29 of FIG. 4), and an attenuation of about 40 dB at a frequency of 550 Hz (point 30 of FIG. 4) appropriately fulfills this dual function (see curve 27 of section C of the frequency response of FIG. 2) while taking into consideration the above mentioned variation of sensitivity of the human ear in function of frequency. Again, FIG. 2 shows that external noise components having a frequency higher than 1300 Hz are greatly attenuated by the bell mode low-pass filter 23.

Signals from the low-pass filters 22 and 23 are supplied to a common output 40 of the external noise isolating filter unit 20.

Connected in parallel with the external noise isolating filter unit 20 is the mechanical valve filter unit 21, for enabling a cardiologist to auscultate mechanical heart valves.

The above mentioned clinical study has also brought to light the importance of enabling cardiologists to auscultate heart valvular prostheses in order to establish diagnosis. Depending on the type of prosthesis (bioprostheses or mechanical prosthesis), certain sounds detected during auscultation can indicate serious problems.

As bioprostheses are made of biological tissue, their acoustic signature is substantially the same as that of natural valves and are located in the same frequency range. The frequency characteristics of normal and pathological sounds produced by this type of valves are consequently the same as those exposed in the section “cardiology” of the above TABLE OF COMMON AUSCULTATORY SOUNDS, in the low, medium, and high frequency ranges. On the contrary, mechanical valves have acoustic signatures concentrated in the frequency range 5–20 kHz. Upon auscultating a mechanical valve, the cardiologist should hear the very high frequency “click”; the absence thereof is usually interpreted as being an abnormal situation, very serious in certain cases. For example, the absence of the “click” can result from the formation of a thrombus. Therefore, it is a requirement for an electronic stethoscope used in cardiology to enable auscultation of very high frequencies.

As illustrated in FIG. 5, the mechanical valve filter unit 21 comprises a band-pass filter 31, a switch unit 32 and a frequency detector 33. Filter 31 acts in the frequency range 1.3–20 kHz (see curve 34 of section D of the frequency response of FIG. 2). It has been found that a band-pass filter 31 adjusted to produce an attenuation of about 40 dB at a frequency of 2.5 kHz (point 35 of FIG. 5), and attenuation of about 20 dB in the range 5–10 kHz (section of curve between points 36 and 37 of FIG. 5), and an attenuation of about 40 dB at a frequency of 30 kHz (point 38 of FIG. 5) will allow the cardiologist to appropriately auscultate mechanical heart valves. As the sensitivity of the human ear is higher in the frequency range of 1.3–10 kHz, filter 31 provides for an attenuation of at least 20 dB over that range.

The signal from band-pass filter 31 is supplied to a frequency detector 33. When frequencies higher than 1300 Hz are present in this signal, the frequency detector 33 senses them and closes the switch unit 32 to supply the signal from the band-pass filter 31 to the output 39 of filter unit 21. Therefore, the mechanical valve filter unit 21 is active only when a given level of frequency components higher than 1300 Hz are detected whereby filter 21 eliminates any ambient or electronic noise of such frequency when the patient is not wearing a mechanical heart valve.

The signals from the output 40 of the external noise isolating filter unit 20 and from the output 39 of the mechanical valve filter unit 21 are added to each other through an adder 41 (FIG. 1) before being supplied to an audio amplifier 42.

As shown in FIGS. 1, 4 and 5, a mode selector 43 enables the physician or other medical practitioner to select the mode of operation of the electronic stethoscope 10. Mode selector 43 comprises a first output 44 to enable or disable the diaphragm mode low-pass filter 22, a second output 45 to enable or disable the bell mode low-pass filter 23, and a third output 46 to enable or disable the frequency detector 33 and thereby enable or disable the mechanical valve filter unit 21. The physician or other medical practitioner can therefore select the diaphragm or bell mode with or without the mechanical valve mode.

As a non-limitative example, selection of the diaphragm mode through selector 43 could enable operation of the mechanical valve filter unit 21 when frequencies higher than 1300 Hz are present in the signal. With the diaphragm mode selected, it will be difficult for a cardiologist auscultating low frequency sounds produced by natural heart valves to concentrate on these low frequency sounds in the presence of a mechanical heart valve producing high frequency sounds of higher intensity. For a selective listening of low frequency sounds, the cardiologist can select through the mode selector 43 the bell mode which is a closed frequency range mode in which the mechanical valve filter unit 21 is inactive. Moreover, as indicated by curve 27 of FIG. 2, the bell mode accentuates the low frequencies located between 50 and 100 Hz and attenuates the medium frequencies between 100 and 1300 Hz. This additional feature enables a physician or other medical practitioner to concentrate on low frequency sounds in many situations in which medium, high and very high frequencies are present.

Referring back to FIG. 1, the signal from the adder 41 is amplified by the audio amplifier 42 and reproduced by means of earphones 47.

In order to protect the inner ear of the physician or other medical practitioner, a protecting unit 48 prevents harmonic distortion of the signal and minimizes the undesirable effects of the noise generated by preauscultation manipulations of the probe and the movements (perceptible to the human eyes) of the physician and/or patient. For that purpose, the inner ear protecting unit 48 comprises a detector 49 for detecting the amplitude level of the signal from the audio amplifier 42 and for activating a pulse generator when the signal level is higher than a given amplitude level threshold. Pulse generator 50, when activated, produces a train of pulses that switches the audio amplifier 42 on and off to reduce the amplitude level of the signal supplied to the earphones 47. Switching the audio amplifier 42 on and off also gives to the user the impression that the stethoscope operates.

A power supply 51 supplies with electric energy the various circuits of the electronic stethoscope 10, as schematically indicated by the arrows 53.

As can be appreciated, the frequency response of FIG. 2 is divided into three main sections, namely section A, section B or C, and section D respectively controlled through a corresponding dedicated filter unit. More specifically, section A is controlled by the anti-tremor filter unit 14, section B by the diaphragm mode low-pass filter 22, section C is controlled by the bell mode low-pass filter 23, and section D by the mechanical valve filter unit 21. The filter units 14, 22, 23 and 21 have been optimized with the help...
of specialists in different fields of the medical profession having auscultated a plurality of patients presenting various pathologies. This collaboration enabled precise definition of the specifications of the frequency response of FIG. 2.

It should be mentioned that the frequency responses, in particular the frequency bandwidth of the anti-tremor filter unit 14, the external noise isolating filter unit 20 and the mechanical valve filter unit 21 can be adjusted in function of the specialty of the user, for example cardiology, pneumology, measure of blood pressure, etc., in order to minimize the noise of biological nature which do not present interest for the specialist. The frequency response of FIG. 2 corresponds to an electronic stethoscope particularly well suited for cardiology.

The noise of electronic nature has been minimized by way of a judicious choice of electronic components providing the overall circuit with a very low level of background noise.

Although the present invention has been described hereinabove by way of a preferred embodiment thereof, this embodiment can be modified at will, within the scope of the appended claims, without departing from the spirit and nature of the invention.

What is claimed is:

1. An electronic stethoscope comprising:
   first means for sensing sounds of interest produced within
   a patient’s body and for converting said sounds to an
   electric signal, wherein said first means is manipulated
   by a user’s hand, said electric signal includes low
   frequency noise generated by an involuntary trembling
   motion of the user’s hand upon manipulating the first
   means, and said noise and sounds both have frequency
   components situated within a common low frequency
   range;
   a filter unit for attenuating said electric signal in the
   common low frequency range, said filter unit comprising
   second means for filtering from said electric signal
   a substantial part of the noise components in lower
   frequencies of said range, and third means for passing
   a substantial part of the sound components in higher
   frequencies of said range; and
   fourth means for reproducing said sounds in response to
   the electric signal from the filter unit to enable the user
   to hear and listen to said sounds;
   wherein:
   said common low frequency range comprises the fre-
   quencies lower than 75 Hz; and
   said filter unit produced at attenuation of about 40 dB
   at a frequency of 30 Hz and an attenuation of about
   3 dB at a frequency of 70 Hz, and comprises serially
   interconnected first and second high-pass filters, said
   first high-pass filter producing an attenuation of
   about 3 dB at a frequency of 60 Hz and an overshoot
   of about 3 dB at a frequency of 80 Hz, and said
   second high-pass filter producing an attenuation of
   about 3 dB at a frequency of 80 Hz.

2. An electronic stethoscope comprising:
   first means for sensing sounds of interest produced within
   a patient’s body and for converting said sounds of
   interest to an electric signal;
   second means for reproducing said sounds of interest in
   response to said electric signal from the first means to
   enable a user to hear and listen to said sounds of
   interest; and
   third means for detecting an amplitude level of said
   electric signal for momentarily and repeatedly inter-
   rupting operation of the second means when the
   detected amplitude level of said electric signal is higher
   than a predetermined amplitude level threshold to pre-
   vent said second means from producing sounds of too
   high intensity susceptible to harm the inner ear of the
   user;
   wherein said third means comprises a pulse generator for
   producing pulses, and an amplitude level detector for
   activating said pulse generator when the amplitude
   level of the electric signal is higher than said prede-
   termined amplitude level threshold, and wherein said
   second means comprises an electric signal audio ampli-
   fier supplied with the pulses from said pulse generator
   and switched on and off in response to said pulses in
   order to reduce the level of the reproduced sounds
   while giving to the user the impression that the stetho-
   scope operates.

3. An electronic stethoscope comprising:
   first means for sensing sounds of interest produced within
   a patient’s body and for converting said sounds of
   interest to an electric signal;
   second means for reproducing said sounds of interest in
   response to said electric signal from the first means to
   enable a user to hear and listen to said sounds of
   interest, said second means comprising an audio ampli-
   fier for amplifying said electric signal and earphones
   for reproducing the amplified electric signal from the
   audio amplifier; and
   third means for detecting an amplitude level of the
   amplified electric signal from the audio amplifier; and
   fourth means for momentarily and repeatedly switch-
   ing the audio amplifier off when the detected amplitude
   level of said amplified electric signal is higher than a
   predetermined amplitude level threshold to prevent
   said earphones from producing sounds of too high
   intensity susceptible to harm the inner ear of the user.

4. An electronic stethoscope as recited in claim 3, wherein:
   said first means is manipulated by a user’s hand, said
   electric signal includes low frequency noise generated
   by an involuntary trembling motion of the user’s hand
   upon manipulating the first means, and said low fre-
   quency noise and sounds of interest both have frequency
   components situated within a common low frequency
   range;
   said second means comprises a filter unit for attenuating
   said electric signal in the common low frequency
   range, said filter unit comprising fifth means for filter-
   ing from said electric signal a substantial part of the
   noise components in lower frequencies of said range,
   and sixth means for passing a substantial part of the
   sound components in higher frequencies of said range.

5. An electronic stethoscope as recited in claim 3, wherein:
   said first means also senses external ambient sounds
   whereby said electric signal includes noise generated
   by said external ambient sounds, said noise and sounds
   of interest both have frequency components situated
   within a common frequency range;
said second means comprises a filter unit for attenuating said electric signal in the common frequency range, said filter unit having a noise-attenuating frequency response for optimizing both attenuation of said noise components and passing of said sound components, taking into consideration the variation of sensitivity of the human ear in function of frequency.

6. An electronic stethoscope as recited in claim 3, wherein:

said sounds of interest comprise sounds produced by a mechanical heart valve having frequency components situated within a given high frequency range; and

said second means comprises:

fourth filtering means interposed between said first means and said audio amplifier for passing said frequency components situated within the given high frequency range from the first means to the audio amplifier; and

fifth means responsive to detection of said frequency components situated within the given high frequency range for transmitting said frequency components situated within the given high frequency range from the fourth filtering means to the audio amplifier for reproduction of the sounds of said mechanical heart valve.

* * * * *
UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 5,602,924
DATED : Feb. 11, 1997
INVENTOR(S) : Durand et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the cover page, in [75] Inventors, "Grenien" should read --Grenier--.

In column 5, line 28, "nois&" should read --noise--.

In column 11, line 50, claim 1, "produced" should read --produces--.

Signed and Sealed this Fourteenth Day of October, 1997

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks
ELECTRONIC STETHOSCOPE WITH DIAGNOSTIC CAPABILITY

Inventor: Cicero H. Malilay, 3586 S. Sepulveda Blvd. #7, Los Angeles, CA (US) 90034

Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

Filed: Mar. 8, 1999

Int. Cl. 7 A61B 7/04; A61B 7/02
U.S. Cl. 381/67; 181/131
Field of Search 381/67; 181/126; 181/131; 600/510, 522, 523; 73/591

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A self-contained, hand-held electronic stethoscope including built-in chestpiece, speaker and visual monitor, includes a memory containing prerecorded heart and lung sounds along with a brief description of the malady producing the sounds so that the technician may compare the actual sounds with the prerecorded sounds and observe a suggested diagnosis on the monitor.
ELECTRONIC STETHOSCOPE WITH DIAGNOSTIC CAPABILITY

This invention relates to electronic stethoscopes and in particular to a stethoscope in which the output may be compared both by sound and visually on a scope with various sound signals prerecorded on a memory medium.

BACKGROUND OF THE INVENTION

Various pathological conditions of a patient are revealed by auscultation examination. A normal heart and lungs produce normal sounds which are detected by the stethoscope, and if any abnormalities are detected proper corrective steps may be taken. Therefore, it is extremely important for a medical diagnostician to recognize and understand normal and abnormal heart and lung sounds.

There are many heart sounds that must be learned by the diagnostician. The human heart has four chambers. During the diastolic or relaxed period, blood flows through the tricuspid valve into the right ventricle and oxygenized blood flows through the mitral valve into the left ventricle. At the end of this very short diastolic period the mitral valve closes followed by the tricuspid valve and the heart muscle contracts in systole while blood is pumped from the right ventricle through the pulmonary valve and blood is pumped from the left ventricle through the aortic valve. There is a sound, called S1, that occurs at the closure of the mitral and tricuspid valves and a sound, S2, that occurs at the closure of the aortic and pulmonary valves.

With the presence of heart disease the individual sounds are often split and may be heard as two sounds on each of the two basic S1 and S2 sounds. And in addition to the basic sounds, there are pathologic sounds which may be caused by blood passing through a tight valve or a pathologically enlarged valve opening. And certain disease processes may cause rubbing sounds produced by rubbing of the heart wall on the tissue covering that surrounds the heart. Certain diseases can change or vary the heart sounds. For example, if S1 appears to be louder than S2, it suggests a tightening of the mitral valve or mitral stenosis, whereas an unusually soft S2 suggests mitral regurgitation. Heart disease is suggested if any component separation occurs during expiration, if separation seems excessive, or if one component is persistently missing.

Lung sounds also have two components, that produced by inspiration and that by expiration. With a presence of disease in the lungs the normal lung sounds are disrupted and certain pathologic crackles, rates and wheeze sounds are produced which, in most instances, would point to a certain disease going on in the patient’s pulmonary and even systemic system.

The foregoing material discusses only a small fraction of the various sounds that may be detected with a stethoscope. There is a multitude of murmurs, hums and clicks that may be heard at various body locations while in various positions. It is thus apparent that the science of auscultation is difficult and that certain medical technicians, such as ambulance technicians or student who may not have thoroughly mastered the science, would benefit greatly from a stethoscope that included a diagnostic capability.

Briefly described, this invention is for a self-contained electronic stethoscope in a housing that includes a prerecorded record of typical sounds, a recorded image of the external pulse recordings of the sound and a suggested diagnosis. The electronic stethoscope normally outputs into a small speaker and to a small oscilloscope for viewing the signal, and depressing a momentary contact switch will divert the prerecorded record output to the speaker and scope for comparison with the stethoscope sounds.

DESCRIPTION OF THE DRAWINGS

In the drawings which illustrate the preferred embodiment of the invention.

FIG. 1 is a schematic drawing of the electronic stethoscope with diagnostic capability;

FIG. 2 is a perspective view of the stethoscope housing; and

FIG. 3 is a top plan view thereof.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The invention is for an electronic stethoscope that has the capability of diagnosing physical problems by providing a means for comparing a stethoscope sound and oscilloscope image with a typical sound and identified image that has been prerecorded on a magnetic memory disc within the hand held stethoscope housing containing amplifying circuitry, the prerecorded memory and a battery for supplying power.

The self-contained circuitry of the stethoscope is illustrated in FIG. 1 and comprises a microphone 10 located in the stethoscope chest piece, immediately followed by wide band low power amplifier 12 the output of which is applied to the switch 14. Switch 14 preferably is comprised of four ganged, single-pole, single-throw switches which are connected into a spring loaded, momentary contact, single double-pole, double-throw configuration so that, in its normal state, one pole couples the amplifier 12 to a speaker for a sound output and the second pole couples the amplifier 12 to a monitor for a visual output of the waveform. When depressed, the first pole of switch 14 couples a prerecorded sound to the speaker and the second pole couples it to the monitor.

Thus, the output of amplifier 12 is coupled to terminal "a" of the switch 14 and normally passes to pole 16 of the switch. Pole 16 of switch 14 is connected to pole 20 of a double-pole double-throw switch 22 which, in a first position passes the signal from amplifier 12 to a second amplifier and a speaker and, in the second position, diverts the signal to the amplifier and speaker through a low pass filter 24 which may be switched on to eliminate all high frequency sounds above approximately 500 Hertz.

The output of the switch 22 is taken from the second pole 26 and after passing through a "privacy" phone jack 28, is applied to the second or power amplifier 30, the output of which is applied through a volume control 32, having an "ON-OFF" power switch, to a speaker 34. The output of amplifier 12 is also coupled to terminal "c" of the switch 14 and normally passes to pole 18 of the switch which is connected to the "X" or vertical deflection input on a small monitor 36 having, for example, a one or two inch oscilloscope tube.

Various heart and lung sounds are prerecorded along with a very short diagnosis of the defect causing the sound. All the heart and lung sounds and the associated suggested diagnoses are recorded on a miniature diskette which can be easily accommodated with the associated circuitry within the hand held housing of the stethoscope. The approximate sector of the expected recorded sound on the diskette is selected by depressing a button on the housing and the recording may be "inched" forward and backward to find the
desired location by an “up” or “down” sliding of the button of the spring biased switch 14 on the side of the housing.

The miniature memory diskette is contained in the memory and microprocessor, the output of which is converted into analog and applied to input terminals “b” and “d” of the switch 14 so that, when switch is momentarily depressed, the prerecorded signals are applied to the speaker 34 and to the monitor 36.

FIG. 2 is a perspective view illustrating one end surface and the rear surface of the stethoscope that contains the selection controls and the audio and visual outputs and FIG. 3 is a top plan view illustrating the chestpiece on the stethoscope.

The stethoscope is contained in a hand-held size housing 40 approximately three inches square and one inch thick. Centered on one of the square surfaces is a funnel shaped chestpiece 42 about two inches long and containing a very thin diaphragm near its narrow end that is backed by the microphone 10 (not shown). A rubber ring 44 is stretched over the rim of the chestpiece to assure a tight seal to the skin of a patient.

On one side of the housing 40 are two controls: The volume control 32 which regulates the audio volume, and the switch 14 which is depressed to momentarily switch on the prerecorded sound from the memory 38 and which also may slide up and down for making forward and backward adjustments in the memory location.

The square surface opposite the chestpiece 42 contains the phone jack 28, the small speaker 34, and the monitor 36 which may have a two-inch or three-inch oscilloscope tube. Also on this surface are seven buttons 46, one of which is the low pass filter switch 22, and the remaining six are for selecting the various pre-recorded subjects on the disk in the memory 38. For example, the six buttons may be labeled Pulmonary Valve, Aortic Valve, Tricuspid Valve, Mitral Valve, Lungs, Blood Vessels. If Blood Vessels button has been depressed the switch button 14 may be moved so that Carotid Artery is displayed on the monitor.

In use, the stethoscope is turned ON with the power switch on the volume control 32 and the chestpiece is pressed at the appropriate body locations of a patient. The sounds picked up by the microphone 10 may be heard by earphones plugged into the phone jack 28 or they may be amplified by amplifier 30 and heard through speaker 34 while a visual representation of the sounds are seen by the monitor 36. If the technician suspects any disorders, he may press the appropriate button 46 and adjust the sliding switch 14 to the location at which matching sounds are heard on the earphones or speaker and seen on the monitor from the prerecorded diskette. For each prerecorded sound visual, there is a brief message suggesting the problem; for example, the technician may have found coincidence between a patient's sound with a pre-recorded sound labeled “Mitral Regurgitation” indicating that the patient’s examination showed a probability of a weak mitral valve and having a backward flow of blood through the valve into the left atrium.

1. A claim: An electronic stethoscope with diagnostic capability comprising:

   a housing capable of being held in one hand, said housing having at least one side surface between two opposing surfaces;

   a chestpiece extending from a first surface of said housing, said chestpiece containing a microphone;

   a first amplifier within said housing and coupled to said microphone;

   a monitor and a second amplifier with a speaker within said housing and coupled to said first amplifier, said monitor for visually displaying the sounds from said first amplifier;

   a memory within said housing, said memory containing a recording of pre-recorded heart and lung sounds, each sound in said memory accompanied by a brief description of a malady suggested by the sound; and

   a spring-loaded, double-pole, double-throw switch attached to the side surface within said housing, said switch connected to normally pass the sounds from said microphone to said speaker and said monitor, and whereas depressing a button on said switch disconnects the sounds from said microphone and substitutes the prerecorded sounds from said memory;

   a phone jack in the circuit between said spring-loaded, double-pole, double-throw switch and said second amplifier;

   a low pass filter, said filter selectively activated by a second double-pole, double-throw switch in the circuit between said spring-loaded, double-pole, double-throw switch and said phone jack.

2. The electronic stethoscope claimed in claim 1 including means on an exterior surface of said housing for accessing sections of said memory to be selected.

3. The electronic stethoscope claimed in claim 2 wherein said means for accessing comprise a plurality of buttons on the surface with the monitor display, one of said buttons controlling said second double-pole, double-throw switch.

4. The electronic stethoscope claimed in claim 1 wherein the sliding of the button on said spring-loaded, double-throw, double-pole switch controls minor adjustments to the selection of said memory.

   * * * * *
ELECTRONIC STETHOSCOPE SYSTEM FOR TELEMEDICINE APPLICATIONS

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ABSTRACT
An electronic stethoscope includes a housing configured for hand-held manipulation, a transducer supported by the housing and configured to sense auscultation signals at a first location, and a headset coupled to the housing and configured to deliver audio corresponding to the auscultation signals through earpieces on the headset. The electronic stethoscope further includes a processor disposed in the housing and configured to convert the auscultation signals to first digital signals representative of the auscultation signals and to wirelessly transmit the first digital signals from the electronic stethoscope via a secure digital network to a second location such that the audio corresponding to the auscultation signals is provided to headsets of one or more additional electronic stethoscopes at the second location in substantial real time with the sensing of the auscultation sounds at the first location.
ELECTRONIC STETHOSCOPE SYSTEM FOR TELEMEDICINE APPLICATIONS

CROSS REFERENCE TO RELATED APPLICATIONS


TECHNICAL FIELD

[0002] The present invention relates to telemedicine systems. More specifically, the present invention relates to electronic stethoscopes that transmit signals over a telemedicine system in substantial real-time via a secure digital network.

BACKGROUND

[0003] A variety of devices have been developed to detect sounds produced by the body, such as heart and lung sounds. Known devices range from primarily mechanical devices, such as a stethoscope, to various electronic devices, such as microphones and transducers. The stethoscope, for example, is a fundamental tool used in the diagnosis of diseases and conditions of the cardiovascular system. It serves as the most commonly employed technique for diagnosis of such diseases and conditions in primary health care and in circumstances where sophisticated medical equipment is not available, such as remote areas.

[0004] Clinicians readily appreciate that detecting relevant cardiac symptoms and forming a diagnosis based on sounds heard through the stethoscope, for example, is a skill that can take years to acquire and refine. The task of acoustically detecting abnormal cardiac activity is complicated by the fact that heart sounds are often separated from one another by very short periods of time, and that signals characterizing cardiac disorders are often less audible than normal heart sounds.

SUMMARY

[0005] In one aspect, the present invention relates to a telemedicine system including a first electronic stethoscope comprising a housing configured for hand-held manipulation, a transducer that senses auscultation signals at a first location, and a headset that delivers audio corresponding to the auscultation signals through earpieces on the headset. The telemedicine system further includes a second electronic stethoscope comprising a housing configured for hand-held manipulation, a transducer, and a headset that delivers audio through earpieces on the headset. The first electronic stethoscope includes a processor that converts the auscultation signals to digital signals representative of the auscultation signals, and an antenna to wirelessly transmit the digital signals to a second location via a secure digital network. The second electronic stethoscope includes an antenna that receives the digital signals representative of the auscultation signals at the second location via the secure digital network, and a processor that converts the digital signals to audio corresponding to the auscultation signals and delivers the audio through earpieces on the headset of the second electronic stethoscope in substantial real-time with the sensing of the auscultation sounds at the first location.

[0006] In another aspect, the present invention relates to an electronic stethoscope including a housing configured for hand-held manipulation, a transducer supported by the housing and configured to sense auscultation signals at a first location, and a headset coupled to the housing and configured to deliver audio corresponding to the auscultation signals through earpieces on the headset. The electronic stethoscope further includes a processor disposed in the housing and configured to convert the auscultation signals to first digital signals representative of the auscultation signals and to wirelessly transmit the first digital signals from the electronic stethoscope via a secure digital network to a second location such that the audio corresponding to the auscultation signals is provided to headsets of one or more remote electronic stethoscopes at the second location in substantial real-time with the sensing of the auscultation sounds at the first location.

[0007] In another aspect, the present invention relates to a telemedicine system including a local electronic stethoscope configured to sense auscultation signals from a patient and convert the auscultation signals to digital signals representative of the auscultation signals. The telemedicine system further includes one or more additional electronic stethoscopes, and a secure network interface connecting the local electronic stethoscope to the one or more additional electronic stethoscopes via a secure digital network. Each of the one or more additional electronic stethoscopes is configured to receive the digital signals representative of the auscultation signals via the secure digital network and to convert the digital signals to audio corresponding to the auscultation signals. The audio is delivered through earpieces on a headset of each of the one or more additional electronic stethoscopes in substantial real-time with the sensing of the auscultation sounds by the local electronic stethoscope.

[0008] While multiple embodiments are disclosed, still other embodiments of the present invention will become apparent to those skilled in the art from the following detailed description, which shows and describes illustrative embodiments of the invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 is a diagrammatic view of a telemedicine system according to an embodiment of the present invention.

[0010] FIG. 2 is a perspective view of an embodiment of an electronic stethoscope suitable for use in the telemedicine system shown in FIG. 1.

[0011] FIG. 3 is a front view of an embodiment of a system for interfacing with an electronic stethoscope at a patient or specialist site.

[0012] FIG. 4 is a screen shot of an embodiment of a user interface at the patient site.

[0013] FIG. 5 is a screen shot of an embodiment of a user interface at the specialist site.

[0014] FIG. 6 is a screen shot of a graphical user interface that may be displayed on the user interfaces shown in FIGS. 4 and 5.

[0015] FIG. 7 is a perspective view of an embodiment of a wireless chestpiece for use in the telemedicine system shown in FIG. 1.

[0016] FIG. 8 is a perspective view of an embodiment of a wireless headset for use in the telemedicine system shown in FIG. 1.
FIG. 9 is a perspective view of another embodiment of a wireless headset for use in telemedicine systems of the present disclosure.

FIG. 10 is a diagrammatic view of a telemedicine system according to another embodiment of the present invention.

While the invention is amenable to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and are described in detail below. The intention, however, is not to limit the invention to the particular embodiments described. On the contrary, the invention is intended to cover all modifications, equivalents, and alternatives falling within the scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

FIG. 1 is a diagrammatic view of an embodiment of a telemedicine system 10 including bioacoustic sensors 12, a patient site computer 14, a patient site software interface 16, a specialist site computer 22, and a specialist site software interface 24. An optional wireless headset 25 is also shown at the specialist site. The patient site bioacoustic sensor 12 communicates with the patient site computer 14 wirelessly, and interacts with the patient site computer 14 via the patient site software interface 16. The specialist site bioacoustic sensor 12 communicates with the specialist site computer 22 wirelessly, and interacts with the specialist site computer 22 via the specialist site software interface 24. The patient site software interface includes a wireless interface 26 and a network port interface 27, and the specialist site software interface includes a wireless interface 28 and a network port interface 29. The patient site computer 14 and the specialist site computer 22 communicate with each other over the Internet 1.

In short, the bioacoustic sensors 12 communicate with each other via the patient site computer 14, the specialist site computer 22, and the Internet 1 allow a clinician or other medical specialist located remotely from the patient site to hear body sounds sensed from a patient at the patient site in substantial real-time. The transmission is in “substantial real-time” due to any delays resulting from signal processing and transmission between the patient and specialist site stethoscopes. Other sounds and information, such as voice signals, may also be transmitted in substantial real-time between the bioacoustic sensors 12.

FIG. 2 is a perspective view of one embodiment of a bioacoustic sensor, an electronic stethoscope 12, suitable for use in the telemedicine system 10. The electronic stethoscope 12 includes ear tips 30a, 30b, ear tubes 32a, 32b, and a main tube 34. The main tube 34 is coupled to a main housing or chestpiece 36, which supports at least one sensor 38 (not visible in FIG. 2). The sensor 38 is configured to sense sounds produced by matter of biological origin, such as sounds produced by the heart, lungs, vocal cords, or other organs or tissues of the body. In certain embodiments, the sensor 38 may be used to pick up voice sounds from the user of the electronic stethoscope 12 at the patient and/or specialist sites. Other components that may be disposed in or on the main housing 36 include a power source, a microprocessor, signal processing circuitry (e.g., a digital signal processor), a keypad, a graphical user interface, and a communications device (e.g., a radio). In addition, the main housing 36 may include power management circuitry such as that described in U.S. Patent Application Publication No. 2008/0232604, entitled “Power Management for Medical Sensing Devices Employing Multiple Sensor Signal Feature Detection,” which is incorporated herein by reference in its entirety.

The signal processing circuitry of the electronic stethoscope 12 may be configured to perform a variety of functions, ranging from simple to complex. For example, the signal processing circuitry may be configured to perform relatively sophisticated analysis of bioacoustic signals received from the sensor 38, such as body sound profile matching. The signal processing circuitry may perform various forms of statistical analysis on signals produced by the sensor 38. In such configurations, the signal processing circuitry may include a digital signal processor (DSP). As a further example, the signal processing circuitry may perform selective frequency filtering to enhance different types of body sounds sensed by the electronic stethoscope 12. The signal processing circuitry is further configured to convert the signals generated by the sensor 38 to acoustic signals for transmission through the ear tubes 32a, 32b for accurate and faithful reproduction of the body sounds through the ear tips 30a, 30b. In some embodiments, the electronic stethoscope 12 is configured to generate acoustic signals as described in U.S. Pat. No. 6,134,331, entitled “Electronic Stethoscope,” U.S. Pat. No. 7,006,638, entitled “Electronic Stethoscope,” and/or U.S. Pat. No. 7,130,429, entitled “Method and an Apparatus for Processing Auscultation Signals,” each of which is incorporated by reference in its entirety.

In some embodiments, the sensor 38 of the electronic stethoscope is configured to modulate or generate an electrical signal in response to deformation of the transducer. Suitable transducers are those that incorporate piezoelectric material (organic and/or inorganic piezoelectric material) such as piezoelectric film, piezoresistive material, strain gauges, capacitive or inductive elements, a linear variable differential transformer, and other materials or elements that modulate or generate an electrical signal in response to deformation. The sensor 38 may be planar or non-planar, such as in the case of a curved or corrugated configuration. Suitable piezo materials may include polymer films, polymer foams, ceramic, composite materials or combinations thereof. The sensor 38 may incorporate arrays of transducers of the same or different transducer type and/or different transducer materials, all of which may be connected in series, individually, or in a multi-layered structure. Suitable transducers that incorporate plural sensing elements having differing characteristics and/or sensors with tunable sensing characteristics are disclosed in commonly owned U.S. Patent Application Nos. 2007/0113649 and 2007/0113654, each of which is incorporated herein by reference in its entirety.

The sensor 38 may be implemented using technologies other than those that employ electromagnetic energy or piezo materials. For example, the sound to be transduced may move a cantilever that has a highly reflective surface, and a laser or optical beam of light shining on this surface may be modulated. The intensity or other property of the modulated light may be received by a photodetector that outputs an electrical signal for analysis. As a further example, one or more accelerometers may be employed to sense sound signals and produce electrical signals corresponding to the sound signals.

The electronic stethoscope 12 also includes a user interface 40. The user interface 40 may include a number of mode and/or status indicators and mode and/or control switches. The switches may include volume or gain control switches and mode selection switches, for example. The indi-
icators may provide an indication of a selected filter mode, or other information, such as battery and communication link status. Such communication link status indication may be based on the error detection (e.g., CRC and other methods described below) performed by a computer 14, 22 and/or the electronic stethoscope 12 at the patient or specialist site. In preferred embodiments, only the occurrence of an error, and not the lack thereof, is reported. For example, if errors are identified by either the specialist site computer 22 and/or the specialist site electronic stethoscope 12, the specialist site electronic stethoscope 12 may send a signal to the specialist site computer 22 that the data received by the specialist site electronic stethoscope 12 is not the same as the data sent by the patient site electronic stethoscope 12. The indication may then be provided by the user interface 40, which shows the clinician at the specialist site that the sound being heard through the specialist site electronic stethoscope 12 is not a faithful reproduction of the body sound signals sensed by the patient site electronic stethoscope 12. As used herein, the term “faithful reproduction” means a digitally exact replica.

[0026] The electronic stethoscope 12 also includes an integrated communications system to communicate signals wirelessly with the patient site computer 14 or the specialist site computer 22. Information acquired by the electronic stethoscope 12 during auscultation, for example, may be transmitted to the computer 14, 22. The computer 14, 22 may process the information to provide various output data, such as a visual, graphical and/or audible representation of the information (e.g., heart rate indication, S1-S4 heart sounds), and/or diagnostic information regarding anomalous cardiac, lung, or other organ function (e.g., phonocardiogram, frequency spectrogram, cardiac murmurs such as those resulting from valve regurgitation or stenosis, breathing disorders such as pneumonia or pulmonary edema), or other organ pathology.

[0027] The communications system may be used to establish a radio frequency (RF) communication link between the electronic stethoscope 12 and the computer 14 or 22 or other external device (e.g., personal computer, personal digital assistant (PDA), cell phone, netbook, etc.), as will be described in more detail below. The communication link may be implemented using a short-range wireless communication interface, such as an interface conforming to a known communications standard, such as a Bluetooth standard, IEEE 802 standards (e.g., IEEE 802.11), a ZigBee or similar specification, such as those based on the IEEE 802.15.4 standard, or other public or proprietary wireless protocol. For example, in some embodiments, the communications system is a Class 1 or Class 2 Bluetooth radio. Wireless communication may be implemented in manners that utilize one or several of the following energy forms: electromagnetic radiation, optical (including near infrared), and acoustic (including high frequency beyond average hearing limit). In some embodiments, the communications system is employed to establish a secure communications link between the electronic stethoscope 12 and the computer.

[0028] In some embodiments, an antenna (not shown) for the wireless communications system is integrated into the main housing 36. In order to improve the communication link with the electronic stethoscope 12, an aperture 42 may be formed in the metal main housing 36 and covered with a more electromagnetically transparent material. For example, the aperture 42 can be covered with a polymeric member. A flashing light source (e.g., LED) may be mounted in the aperture to indicate that the connection between the electronic stethoscope 12 and the computer is active, and to remind the user of the electronic stethoscope 12 to not cover the aperture 42. A return signal strength indicator may be included on the user interface 40 to provide the strength of the communication link to the user while a connection with the computer is established. In some embodiments, a small parabolic reflector is placed under the antenna to reflect signals transmitted from the antenna normally lost into the tissue of the patient, and to concentrate signals received from the computer captured by the antenna. In an alternative embodiment, the antenna is mounted in one of the ear tubes 32a, 32b or the main tube 34 to locate the antenna higher and improve the line-of-sight with the computer. The antenna may include multiple branches that are mountable on both sides of the ear tubes 32a, 32b to allow unobstructed signal communication under varying body orientations.

[0029] The electronic stethoscope 12 may also include a wired connection port 44 to allow for a wired connection between the electronic stethoscope 12 and the computer 14 or 22 or other external device (e.g., personal computer, personal digital assistant (PDA), cell phone, netbook, etc.). A conductor (electrical or optical) may be connected between the wired connection port 44 of the electronic stethoscope 12 and an appropriate connector on the external device. The wired connection port 44 of the electronic stethoscope 12, and any necessary interface circuitry, may be configured to communicate information in accordance with a variety of protocols, such as FireWire™ (IEEE 1394), USB, or other communications protocols. In addition, the connection port 44 may be configured to connect to a docking station that interfaces the electronic stethoscope 12 with the computer 14 or 22. The attachment of the electronic stethoscope 12 to the cable or docking station can trigger the automatic launch of control/application software on the computer 14 or 22 and/or allow sound or data files stored on the electronic stethoscope 12 to upload or synchronize into the computer 14 or 22. When connected, recharging power may also be delivered to the electronic stethoscope 12 via the wired connection port 44.

[0030] An acoustic transducer or microphone 48 may also be integrated into the top side (i.e., the side facing away from the sensor 38) of the main housing 36. The microphone 48 may be used to receive ambient sounds from the area surrounding the microphone 48. For example, the microphone 48 may be used, in addition to or in lieu of sensor 38, to pick up voice sounds from the user of the electronic stethoscope 12 at the patient and/or specialist sites.

[0031] In some embodiments, the electronic stethoscope 12 includes an integrated electronic storage medium that allows a user to store voice tracks, body sounds, or other recordings in the electronic stethoscope 12 for later review. The electronic storage medium may further include voice recognition data to identify the user or owner of the stethoscope and speech recognition data to identify voice commands so that certain settings (e.g., power, volume) of the electronic stethoscope 12 may be modified in response to voice commands. Speech recognition voice commands may also be used to transfer voice tracks, body sounds, or other recordings or files to a patient medical record database. In some embodiments, the electronic stethoscope is configured to transcribe the content of voice signals into records or other data files (e.g., patient medical records), as described, for example, in U.S. Patent No. 7,444,285 (Forbes). The voice tracks may also be stored with sound tracks relating to sensed body sounds such that the body sounds and voice tracks can be played back...
simultaneously through the ear tips 30a, 30b. In some embodiments, the user interface 40 allows the user to scroll through the body sounds and voice tracks stored in the electronic storage medium for selection and playback. The microphone 48 may also be employed for active ambient noise reduction to remove unwanted surrounding environmental noise from the recorded body and voice signal.

[0032] Referring back to FIG. 1, the electronic stethoscope 12 at the patient site may be linked to or paired with the patient site computer 14 via the secure wireless interface 26 to establish a secure network connection between the patient site electronic stethoscope 12 and the patient site computer 14. Similarly, the electronic stethoscope 12 at the specialist site may be linked to or paired with the specialist site computer 22 via the secure wireless interface 28 to establish a secure network connection between the specialist site electronic stethoscope 12 and the specialist site computer 22. While a single electronic stethoscope 12 is shown at each of the patient and specialist sites, it will be appreciated that a plurality of electronic stethoscopes 12 may be linked to the patient site computer 14 and/or the specialist site computer 22. In some embodiments, the electronic stethoscopes 12 are paired with their respective computers 14, 22 via a personal area network (PAN). One example of a PAN is a Bluetooth network, in which a pairing code is established on one of the electronic stethoscope 12 and computer 14 or 22, and entered on the other of the electronic stethoscope 12 and computer 14 or 22. In some embodiments, an optional wireless headset is also linked to or paired with the specialist site computer 22 or stethoscope 12 via the secure wireless interface 28.

[0033] A secure connection is also established between the network port interfaces 27, 29 of computers 14, 22, respectively, over the Internet I such that the electronic stethoscopes 12 can communicate with each other over a secure network connection. For example, the network port interfaces 27, 29 may exchange certificates, require authentication, or establish secure network keys to establish a secure connection. The data may also be encrypted by the computers 14, 22 prior to sending the data over the Internet I. The secure network key may then be employed to decrypt the data when received. In some embodiments, the network port interfaces 27, 29 allow applications on the computers 14 and 22 to interface with the wireless interfaces 26, 28 remotely across the Internet I.

[0034] In an alternative embodiment, the electronic stethoscopes 12 are configured to communicate with each other directly via a secure connection (i.e., without interfacing with the computers 14 and 22). For example, each electronic stethoscope 12 may be configured with a unique Internet Protocol (IP) address, and the electronic stethoscopes 12 may establish a secure connection with each other directly using a wireless fidelity (WiFi) connection or other wireless connection (e.g., Bluetooth pairing, Cellular connection). As another example, the patient site and/or specialist site may include a plurality of electronic stethoscopes 12 that communicate with each other locally.

[0035] When the electronic stethoscopes 12 are linked over a secure network connection, signals may be sent between the electronic stethoscopes 12, or between the electronic stethoscopes 12 and the computers 14, 22, in substantial real-time. For example, body sounds may be transmitted from the electronic stethoscope at the patient site to the ear tips 30a, 30b at the specialist site in substantial real-time. The body sounds may also be reproduced in substantial real-time by speakers connected to the computers 14, 22. In some embodiments, the electronic stethoscopes 12 at the patient and specialist sites are substantially identical such that the body and other sounds are reproduced substantially identically in the ear tips 30a, 30b at the patient site and the specialist site. In addition, sounds may be recorded and stored by one of the electronic stethoscopes 12 and later played (either from the memory in the electronic stethoscope 12 or from one of the computers 14, 22) at substantially the same time to all networked electronic stethoscopes 12. In some embodiments, the signals transmitted by the patient site electronic stethoscope 12 to the patient site computer 14 and over the Internet I are packetized and enumerated by the patient site electronic stethoscope 12, and undergo an error check at the specialist site to assure faithful sound quality and reliable reproduction at the specialist site electronic stethoscope 12. The error check may be performed by each element of the telemedicine system 10 (i.e., patient site computer 14, specialist site computer 22, and specialist site electronic stethoscope 12) as a further assurance of accurate transmission of data from the patient site electronic stethoscope 12. The error check may be any use suitable data transmission check techniques, including, but not limited to, cyclic redundancy check (CRC), checksum, horizontal and vertical redundancy check, hash function, repetition code, and the like. The system may also incorporate, for example, sample throughput measurements, performed to determine excess data or data starvation in the communication link. In short, the sound packets from the patient site electronic stethoscope 12 are directly relayed (i.e., mirrored) over the Internet I to the specialist site electronic stethoscope 12.

[0036] In preferred embodiments, the telemedicine system 10 includes an error check and validation independent of the underlying communication system or network (e.g., Bluetooth, TCP/IP protocol). The independent error check may be performed at any component of the telemedicine system 10 as a further assurance that the signal is a faithful reproduction of the auscultation sounds from the patient site electronic stethoscope 12. In certain preferred embodiments, interruptions in service of the underlying system are classified according to duration and severity, with all errors resulting in a communication to the user (via one or more components of the telemedicine system) that the signal is not a faithful reproduction. For example, a patient site component may send a packetized or other signal to a specialist site system component every other 500 milliseconds. An interruption in the underlying communication system or network exceeding 500 milliseconds may result in a dropped packet/signal and a resultant indication at the specialist site of degraded sound quality (e.g., via changing color of an indicator).

[0037] In addition, ambient sounds, such as voice signals, can be received by the sensor 38 and transmitted between the electronic stethoscopes 12 in substantial real-time, simultaneously or alternatingly with the body sounds. In alternative embodiments, the electronic stethoscopes 12 can receive voice communications and other ambient sounds through the microphone 48 that are processed and communicated to the remote site. The body sound information is continuously streamed from the patient site electronic stethoscope 12 to the specialist site electronic stethoscope 12, while the ambient sounds are streamed in both directions between the patient and specialist site electronic stethoscopes 12. The patient site electronic stethoscope 12, specialist site electronic stethoscope 12, patient site computer 14, and specialist site computer 22 may each include one or more ring buffers to assure
a continuous stream of information between the electronic stethoscopes 12. In some embodiments, the ambient sounds are μ-law encoded and superimposed over the body sounds generated by the electronic stethoscope 12 at the patient site. Thus, the clinician at the patient site can hear the body sounds from the patient while receiving voice instructions from the specialist at the specialist site, for example. This allows the specialist at the specialist site to have a substantially hands-on experience with the patient. Because the clinician at the patient site receives the sound through the ear tips 30a, 30b, the clinician at the patient site and the specialist at the specialist site can consult privately, rather than having the specialist site communications output through speakers attached to the patient site computer 14, for example. Signal processing may be employed to optimize the sound quality of the voice signals provided through the ear tips 30a, 30b.

[0038] The voice and auscultations sounds reproduced through the ear tips 30a, 30b of the electronic stethoscopes 12 at the patient and specialist sites may be controlled locally at each electronic stethoscope 12. The auscultation and voice signals may be provided to the ear tips 30a, 30b simultaneously, but on separate channels, allowing the clinician to separately control the volume of the auscultation sounds and voice communications. This allows the clinician to optimize the relative volumes of the auscultation and ambient sounds, providing the clinician with a balanced output to the ear tips 30a, 30b that is tailored to the clinician’s preferences. Each electronic stethoscope 12 may further include selectable voice enhancement filters that, for example, enhance certain frequency bands of the voice signals to assist with ambient noise reduction.

[0039] In some embodiments, the transmission of voice signals is selectively controlled while the stethoscopes are linked over the secure network connection. For example, when connected, the body sounds may be constantly transmitted from the patient site to the specialist site, while the voice signals and other ambient sounds are transmitted between the sites only when the clinician chooses to have the voice signals transmitted. For example, in some embodiments the electronic stethoscope 12 utilizes selective frequency filtering during auscultation to suppress frequency bands characteristic of voice signals. In such embodiments, the clinician may initiate the transmission of voice signals by essentially deactivating the frequency filtering or modifying the filter settings (i.e., allowing reproduction and transmission of only certain frequency bands characteristic of voice signals). In some embodiments, transmission of the voice signals is initiated when the clinician presses a button on the user interface 40. The electronic stethoscope 12 may be configured such that the voice signals are transmitted when the button on the user interface 40 is pressed and held (similar to a handheld transceiver or walkie-talkie). The electronic stethoscope 12 may alternatively be configured such that a voice signal transmission mode is activated when the button is pressed and released, and the voice signal transmission mode is deactivated when the button is subsequently pressed and released again.

[0040] The electronic stethoscopes 12 may include an integrated software memory that initially stores the software for the patient site software interface 16 and/or the specialist site software interface 24. For example, the software may be included in each electronic stethoscope 12 when the electronic stethoscope 12 is sold to a consumer. When the electronic stethoscope 12 is paired with the computer 14 or 22, the electronic stethoscope 12 may be configured to automatically load software stored in the software memory onto the computer 14 or 22. When the software is installed on the computers 14, 22, the software allows the electronic stethoscopes 12 to interact with the computers 14, 22, such as by sending information and signals from the electronic stethoscopes 12 to the computers 14, 22 and providing control signals from the computers 14, 22 to the electronic stethoscopes 12.

[0041] Also shown in FIG. 1 is a patient site telediagnostic application 56 and server site telediagnostic application 58. In some embodiments, a video camera is connected to the patient site computer 14 and/or the specialist site computer 22 to allow video communications between the patient site and the specialist site via the telediagnostic applications 56 and 58. This allows, for example, the specialist at the specialist site to see the positioning of the sensor 38 relative to the patient at the patient site and to provide feedback to the patient site about the positioning of the sensor 38. As another example, the video cameras may be used in conjunction with the microphones 48 on each of the electronic stethoscopes 12 to provide video conferencing between the patient site and specialist site.

[0042] FIG. 3 is a front perspective view of an embodiment of a computer 60 that is suitable for use as patient site computer 14 and/or specialist site computer 22. The computer 60 includes a processor 62, a display 64, a camera 66, a keyboard 68, a mouse 70, and a communications adapter 72. The processor 62 is also configured for connection to the Internet to facilitate communications between the patient site and the specialist site. The processor 62 is shown as a laptop computer, but the processor may alternatively be a desktop computer or have any other form. In addition, while a separate display 64 is shown, the display of the laptop computer may also be used. Furthermore, other input devices (e.g., trackball, joystick, etc.) may be integrated into the computer 60 for use in the telediagnostic system 10.

[0043] The processor 62 receives input control signals from the keyboard 68 and mouse 70, and provides video signals to the display 64. In addition, the processor 62 sends signals to and receives signals from the electronic stethoscope 12 via the communications adapter 72. In some embodiments, the communications adapter 72 is a Bluetooth dongle suitable for short-range (e.g., up to 10 m) and medium-range (e.g., up to 100 m) secure communications. The keyboard 68 and the mouse 70 may be used to establish a security code or the like to initiate a secure connection with the electronic stethoscope 12 as described above. The communications adapter 72 may be positioned high on a wall as is shown to improve the line-of-sight and communications link between the electronic stethoscope 12 and the communications adapter 72.

[0044] The camera 66 communicates with the processor 62 to capture video of the patient or specialist site. The processor 62 then interfaces across the Internet 1 via the telediagnostic application 56 or 58 to provide a live video feed to the patient or specialist site. The camera 66 may be a mounted on the top of the display 64 as is shown to provide video communications between the patient and specialist sites as described above. The camera 66 may also be configured for wireless communication with the processor 62 to allow the camera 66 to be moved around the patient or specialist site (e.g., to capture video of location of the sensor 38 on the patient). In some embodiments, the keyboard 68 and/or mouse 70 can be used at one site to control the operation of the camera 66 (e.g., zoom, focus, position, etc) at the other site. This allows, for
example, the specialist at the specialist site to control the video being captured at the patient site.

FIG. 4 is a screen shot of an embodiment of a user interface 80 that may be displayed on the display 64 at the patient site during a telemedicine session. The user interface 80 includes a data display module 82, a video conference module 84, and a stethoscope control module 86. A user of the patient site computer 14 may use the keyboard 68, mouse 70, and/or other input devices to interact with the user interface on the display 64. For example, the user may employ the mouse 70 to select buttons or pull-down menu elements on the user interface 80.

The data display module 82 is a graphical representation of a periodic body sound generated by the patient and sensed by the sensor 38 at the patient site. The signals generated by the sensor 38 are processed by the electronic stethoscope processor and provided to the patient site computer 14 via the integrated antenna. The processor 62 then processes these signals and converts them into appropriate form for display on the data display module 82. The graph can be updated periodically or in substantial real-time while the clinician holds the electronic stethoscope 12 against the patient’s body. The scale used or the axes in the graph can be manipulated using the radio buttons 88 on the data display module.

In some embodiments, the electronic stethoscope processor separates the signals generated by the sensor 38 into a plurality of channels. For example, the electronic stethoscope processor may convert the sensed body sounds to data signals representative of the sensed body sounds and send the data signals to the patient site computer 14 on a first channel, and may convert the sensed body sounds to acoustic signals and send the acoustic signals to the ear tips 30a, 30b on a second channel. Alternatively, the signals generated by the sensor 38 may be sent directly to the patient site computer 14 for conversion to data signals for display the processor 62.

The video conference module 84 displays the video being captured by the camera 66 at the specialist site. This allows the clinician at the patient site to see the specialist at the specialist site, and permits the specialist to demonstrate preferred positioning of the sensor 38 relative to the patient at the patient site, for example. The video conference module 84 also includes a toolbar 90 including a variety of videoconferencing controls. For example, the toolbar 90 may include buttons to control the volume of sound received from the specialist site and the positioning of the video conference on the user interface 80. The toolbar 90 may also include interfaces and tools to start and end the video conference.

The stethoscope control module 86 may include a variety of selectable controls and settings for the electronic stethoscope 12 at the patient site. These settings may be chosen to control the modes, volume, power state, recording settings, and the like of the patient site electronic stethoscope 12. In some embodiments, these settings are also selectable via the user interface 40 on the electronic stethoscope 12. The stethoscope control module 86 may also include options for controlling other modules on the user interface 80. The stethoscope control module 86 may further include selectable options for the communication settings between the electronic stethoscope 12 and the patient site computer 14. For example, the stethoscope control module 86 may allow for adjustment of the packetization settings of the electronic stethoscope 12, or to check and repair the connection settings between the electronic stethoscope 12 and the patient site computer 14.

FIG. 5 is a screen shot of an embodiment of a user interface 100 that may be displayed on the display 64 at the specialist site during a telemedicine session. Similar to the user interface 80, the user interface 100 includes a data display module 102, a video conference module 104, and a stethoscope control module 106. A user of the specialist site computer 22 may use the keyboard 68, mouse 70, and/or other input devices to interact with the user interface on the display 64. For example, the user may employ the mouse 70 to select buttons or pull-down menu elements on the user interface 100.

The data display module 102 is a graphical representation of a periodic body sound generated by the patient and sensed by the sensor 38 at the patient site. The signals generated by the sensor 38 are processed by the electronic stethoscope processor, provided to the patient site computer 14, and sent to the specialist site computer 22. The specialist site computer processor 62 then processes these signals and converts them into appropriate form for display on the data display module 102. The graph can be updated periodically or in substantial real-time while the clinician holds the electronic stethoscope 12 against the patient’s body. The scale used or the axes in the graph can be manipulated using the radio buttons 108 on the data display module.

The video conference module 104 displays the video being captured by the camera 66 at the patient site. This allows the specialist at the specialist site to see the positioning of the sensor 38 relative to the patient at the patient site, for example. The video conference module 104 also includes a toolbar 110 including a variety of videoconferencing controls. For example, the toolbar 110 may include buttons to control the volume of sound received from the patient site and the positioning of the video conference on the user interface 100. The toolbar 110 may also include interfaces and tools to start and end the video conference. The toolbar 110 may also include controls to adjust the camera position at the patient site.

The stethoscope control module 106 may include a variety of selectable controls and settings for the electronic stethoscopes 12 at the patient site and/or the specialist site. These settings may be chosen to control the modes, filtering, volume, power state, recording settings, and the like of the patient and/or specialist site electronic stethoscopes 12. For example, the stethoscope control module 106 may include an interface to control the mode and filter settings on patient site electronic stethoscope 12. The stethoscope control module 106 may also be configured to allow control of some settings on the patient site electronic stethoscope 12, while leaving other settings for only local control. For example, the stethoscope control module 106 may provide volume control for only the specialist site electronic stethoscope 12, while the volume for the patient site electronic stethoscope 12 is controllable at the patient site (e.g., via the stethoscope control module 86 or the user interface 40 on the patient site electronic stethoscope 12). In some embodiments, the specialist site electronic stethoscope 12 may also be configured such that the user interface 40 on the specialist site electronic stethoscope 12 controls settings of the patient site electronic stethoscope 12 when connected over a secure network. The specialist site electronic stethoscope 12 may also be configured to control substantially all of the settings on the patient site.
site electronic stethoscope 12 (i.e., local control at the patient site is essentially disabled), while still allowing the patient site to control of volume. Such local control ensures that volume may be adjusted according to user preference at each location.

[0054] In an alternative embodiment, the clinician at the specialist site may set the specialist site electronic stethoscope 12 to the desired settings and subsequently send the settings of the specialist site electronic stethoscope 12 to the patient site electronic stethoscope 12 (e.g., via the specialist site computer 22 and the patient site computer 14) in one transmission to update the settings on the patient site electronic stethoscope 12.

[0055] The stethoscope control module 106 may further include selectable options for the communication settings between the patient site electronic stethoscope 12 and the patient site computer 14 and/or the specialist site electronic stethoscope 12 and the specialist site computer 22. For example, the stethoscope control module 106 may allow for adjustment of the packetization settings of the electronic stethoscope 12, or to check and repair the connection settings between the electronic stethoscope 12 and the specialist site computer 22.

[0056] The user interface 100 shown and described is merely exemplary and other configurations for the user interface are possible. In one exemplary alternative configuration, shown in FIG. 6, the user interface 100 may include a first graphical user interface 112 that is a feature enhanced image of the housing 36 on the specialist site electronic stethoscope 12, having a control section 114 including each of the buttons and other interfaces on the user interface 40 on the specialist site electronic stethoscope 12. Each button on the control section 114 may be selectable to produce the same function on the specialist site electronic stethoscope 12 as if the corresponding button on the user interface 40 were pressed. A user interface similar to user interface 112 may also be displayed on the user interface 80 to provide on-screen function control for the patient site electronic stethoscope 12.

[0057] When the specialist site electronic stethoscope 12 is connected to and synchronized with the patient site electronic stethoscope 12, the user interface 100 may display a single graphical user interface that is a feature enhanced image of the housing 36 on the patient site electronic stethoscope 12, including each of the buttons and other interfaces on the user interface 40 on the patient site electronic stethoscope 12. This same graphical user interface 112 may also be displayed on the user interface 80. When the patient and specialist site electronic stethoscopes 12 are connected, each button on the graphical user interface 112 may be selectable at either the patient or specialist site to produce the same function on the patient site electronic stethoscope 12 as if the corresponding button on the user interface 40 of the patient site stethoscope was pressed. The graphical user interface 112 provides the clinician at the specialist site with an interface through which certain settings (e.g., mode, filters, etc.) of the patient site electronic stethoscope 12 are controllable.

[0058] The graphical user interface 112 may also include a plurality of connectivity buttons 116 that may be used to control the connection between the specialist site computer and the connected electronic stethoscopes 12. For example, in the embodiment shown in FIG. 6, the connectivity buttons 116 include a “Disconnect Scope” button that allows for disconnection of the local specialist site electronic stethoscope 12 from the specialist site computer 22, a “Disconnect Remote” button that allows for disconnection of the specialist site computer 22 (and desynchronization of the specialist site electronic stethoscope 12) from the patient site electronic stethoscope 12, and a “Talk to Remote” button that activates voice communications between the specialist and patient site electronic stethoscopes 12. When the specialist site electronic stethoscope 12 is not connected to the patient site electronic stethoscope 12, the “Disconnect Remote” and “Talk to Remote” buttons may be inactivated or may not appear on the graphical user interface 112.

[0059] Additionally, the graphical user interface 112 may include an options menu 117 that allows the user to control various options associated with the connected electronic stethoscope 12. For example, in the embodiment shown in FIG. 6, the options menu 117 includes a pull-down menu that allows the clinician to scroll between the stethoscopes connected to the specialist site computer 22. This toggles the active electronic stethoscope 12 active on the graphical user interface 112, allowing the clinician to modify the settings for each of the connected stethoscopes.

[0060] The graphical user interface 112 may further include a visual and/or audio indication that indicates that the sound heard by the clinician at the specialist site electronic stethoscope 12 is a faithful reproduction of the sound from the patient site electronic stethoscope 12. In the embodiment shown in FIG. 6, the graphical user interface 112 includes a fidelity gauge 118 labeled “Stream Integrity” that includes a fidelity indicator 119. The fidelity indicator 119 changes color to 36 to indicate whether faithful sound reproduction is occurring at the specialist site electronic stethoscope 12. For example, the fidelity indicator 119 may be displayed in green when the sound is a faithful reproduction and in red when the sound is not a faithful reproduction. This indication may be based on the error detection (e.g., CRC) performed by the specialist site computer 22 and/or the specialist site electronic stethoscope 12. The error detection may also be performed by the patient site computer 14 and/or patient site electronic stethoscope 12. For example, if errors are identified by either the specialist site computer 22 and/or the specialist site electronic stethoscope 12, the specialist site electronic stethoscope 12 may send a signal to the specialist site computer 22 that the data received by the specialist site electronic stethoscope 12 is not the same as the data sent by the patient site electronic stethoscope 12. The indication may then be provided by the user interface 100, which shows the clinician at the specialist site that the sound being heard through the specialist site electronic stethoscope 12 is not a faithful reproduction of the body sound signals sensed by the patient site electronic stethoscope 12. The specialist site electronic stethoscope 12, the patient site electronic stethoscope 12, and/or the user interface 80 may also provide an indication of faithful sound reproduction. In alternative embodiments, the lack of error is reported to system components.

[0061] While the electronic stethoscope 12 has been described with regard to a stethoscope having a chestpiece, main tube, and binaurals connected to ear tips, the electronic stethoscope used in the telemedicine system 10 may have other configurations. For example, FIG. 7 illustrates a wireless chestpiece 120 and FIGS. 8 and 9 illustrate wireless headsets 122 usable in association with the telemedicine system 10.
Cine system 10 in substantially the same way as the electronic stethoscope 12. In particular, the wireless chestpiece 120 is configured to connect with the computers 14, 22 via a secure network connection. Components that may be disposed in the chestpiece 120 include a power source, signal processing circuitry, and a communications interface. A sensor 124 (not shown) is supported at one end of the wireless chestpiece 120, and an antenna 126 is mounted at an end of the wireless chestpiece 120 opposite the sensor 124. The sensor 124 may have properties and configurations similar to those described above with regard to sensor 38. The wireless chestpiece 120 can also include electrodes (not shown) for inductance or capacitance recharging of the power source when coupled to a wireless headset (as described below). The wireless chestpiece 120 may further include one or more magnets configured to attract to one or more magnets in a wireless headset 122, enabling releasable attachment between the chestpiece and the headset.

In some embodiments (not shown), an antenna is integrated into the housing as described above. In the embodiment shown, the antenna 126 is configured to swivel or rotate about pivot 128 to allow the antenna 126 to be positioned for maximum signal coupling during use. The antenna 126 can also be positioned to minimize clearance during storage. In some embodiments, the antenna 126 is a high performance antenna for large signal range (e.g., greater than 100 m), thereby maximizing the mobility of the wireless chestpiece 120.

A wireless headset 122 is configured to receive signals from an electronic stethoscope, biosensor, or other source via a secure and/or network connection. Components that may be disposed in the headset 122 include a power source, signal processing circuitry, an antenna and a communications interface, all similar to the modules and components integrated into chestpiece 36 described above. Additional components that may reside in the headset 122 include a user interface, a control module, and a microphone.

The wireless headset 122 may have various configurations, including over-the-ear and in-ear designs. In the embodiments shown in FIGS. 8 and 9, the wireless headset 122 includes ear tips 130a, 130b for in-ear use. In some embodiments, the ear tips 130a, 130b are substantially the same as ear tips 30a, 30b in FIG. 2 to provide consistent sound quality to the user between the electronic stethoscope 12 and the wireless headset 122. As depicted in FIG. 9, the wireless headset 122 includes a control housing 140, ear tubes 132a, 132b, and yolk 135. The control housing 140 can include a power source, signal processing circuitry, an antenna, a communications system, a user interface, a control module, and a microphone.

If provided, the headset communications system may be used to establish a radio frequency (RF) communication link between the wireless headset and an electronic stethoscope chestpiece, a biosensor, a computer, or any other external device configured for wireless communication (e.g., personal computer, personal digital assistant (PDA), tablet, cell phone, netbook, digital music player, etc.). As used herein, a paired or pairable device means any article configured to wirelessly communicate with the wireless headset. The communication link may be implemented using a short-range wireless communication interface, such as an interface conforming to a known communications standard, such as a Bluetooth standard, IEEE 802 standards (e.g., IEEE 802.11), a ZigBee or similar specification, such as those based on the IEEE 802.15.4 standard, or other public or proprietary wireless protocol. For example, in some embodiments, the communications system is a Class 1 or Class 2 Bluetooth radio. In some embodiments, the communications system is employed to establish a secure communications link between the wireless headset 122 and a pairable device.

In some embodiments, the signals transmitted by the paired device to wireless headset 122 are packetized and enumberated by the paired device, and undergo an error check or other validation at the wireless headset 122 to assure faithful sound quality and reliable reproduction. The error check may use any suitable data transmission check techniques, including, but not limited to those described above. As detailed above, the error check can be in addition to the underlying communication protocol.

In particularly useful embodiments, the wireless headset 122 can serve as a network interface and/or personal area network (PAN) hub (e.g., a Bluetooth host or other wireless network access point). As a network interface, the wireless headset 122 can establish an authentication code, (e.g., a Bluetooth PIN/pairing code, a wireless network password, etc.), which is entered on or otherwise communicated by the desired pairable device. Alternatively, the desired pairable device can establish the authentication code which can then be entered or otherwise communicated by the wireless headset 122. Accordingly, the wireless headset 122 can function as both a network host and network client. The wireless headset 122 may include an integrated electronic storage medium that allows for storage and retrieval of the identity and/or location of the paired device to which the headset last established a communication link.

In another aspect, the wireless headset may be paired with a device via communication and verification of data representative of the movement of the headset and the device (i.e., an acceleration profile). For example, the wireless headset 122 and the pairable device may each include an accelerometer (e.g., a two or three axis accelerometer or multiple single axis accelerometers) configured to create an acceleration profile based on data representative of movement of the respective device. The acceleration profile, or portions thereof, can serve as an authentication code for network interface communication. In one implementation of the pairing method, the wireless headset 122 and the pairable device may be grasped and moved (e.g., rotated, shaken, etc.) in concert, which will generate a similar, if not identical, acceleration profile for each device. Alternatively, the headset 122 and the pairable device may separately be moved along the same path at the same velocities. In one aspect, the wireless headset 122 can broadcast the acceleration profile/authentication code. The pairable device can then, via processor or other component, verify that the headset acceleration profile matches the acceleration profile of the pairable device. In other implementations, the desired pairable device can communicate the acceleration profile, which can then be entered or otherwise communicated to the wireless headset 122 for verification.

Profile matching may be accomplished by comparing all or a portion of the acceleration profiles. In one exemplary embodiment, the matching includes comparing the absolute magnitude of acceleration experienced by each device. In another example, in the temporal sequences of “zero-crossings” (e.g., change of the direction of acceleration of the sensor), are compared and verified. In yet other implementations, the temporal sequence and the magnitude are
compared. The similarity required for a match (i.e., the acceptable severity or occurrence of differences between the profiles) can be tailored to the particular application, but is typically at least the Bluetooth pairing standard. It should also be appreciated that at least portions of acceleration profiles could also be used to authenticate and pair two or more wearable devices.

[0071] Due at least in part to the wireless headset operating as a network interface, the paired device can be a wireless chestpiece 120 or any other stethoscope chestpiece including a communication module, including chestpiece 36 above. The biosensor can be, for example, the combined ECG/PCG sensor described in co-appending application Attorney Docket No. 66786US002, filed Jun. 15, 2012 and entitled “ENHANCED AUSCULTATORY SENSOR AND ANALYSIS FOR PATIENT DIAGNOSIS”. In particularly suitable embodiments, the headset 122 is communicatively coupled to a paired device via a Bluetooth network connection.

[0072] The control housing 140 can include, among other components, a user interface 142 and a control module. The control housing 140 may also contain one or more of the power source, signal processing circuitry, antenna and communications interface. In alternative embodiments, one or more of the previously recited components may be integrated into the yolk 135. The user interface 142 can include similar functionality as user interface 40 and may include a number of mode and/or status indicators and mode and/or control switches. The switches may include volume or gain control switches and mode selection switches, for example. The indicators may provide an indication of, for example, battery or communication link status. Similar to the indicators on chestpiece 36, the indicators may indicate a faithful reproduction of sound form the paired device.

[0073] The wireless headset 122 may further include a control module disposed within the control housing 140. The control module may include a variety of selectable controls and settings for the paired device, typically an electronic stethoscope or biosensor. These settings may be chosen to control the modes, filtering, volume, power state, recording settings, and the like of paired device. The headset control module may further include selectable options for the communication settings between the wireless headset 122 and the paired device. For example, the headset control module may allow for adjustment of the packetization settings of a paired electronic stethoscope, or to check and repair the connection settings between the electronic stethoscope and the wireless headset 122. In certain implementations, the control housing 140 may be movable (e.g., rotatable) relative to the ear tubes 132a, 132b to reduce the overall volume of the wireless headset 122 and protect certain components in the control housing 140 for storage or handling. Further, one of the yolk 135 or the control housing 140 may include an internal volume sufficient to retain portions of ear tubes 132a, 132b. For example, the ear tubes, or portions thereof, may be moved along rails into the housing to create a reduced wireless headset 122 profile.

[0074] The wireless headset 122 may also include a microphone 134 for receiving voice sounds from the user. In FIG. 8, the microphone 134 is coupled to an adjustable support 136 that allows the microphone 134 to be repositioned relative the user. As depicted in FIG. 9, the microphone is disposed partially within control housing 140. Other suitable locations, such as the headset yolk 135 or the outer surface of the control housing 140, are also contemplated. The signals received by the microphone 134 may be superimposed over the body sounds received by the wireless headset 122 and/or sent over the communication link, as described above. The microphone 134 may further allow the user to communicate verbally with, for example, the headset on a paired electronic stethoscope in lieu of or in addition to transmitting of body sounds.

[0075] The wireless headset 122 can further include mechanisms for releasably retaining the wireless chestpiece 120 or other paired device. Various modes of connection between the headset and the chest piece may be employed. For example, and according to the depicted embodiment, the wireless headset 122 includes magnets 150 that are configured to attract magnets or magnetized material on the paired device to enable releasable attachment therebetween. Alternatively, various mechanical means can be employed to releasably secure the chestpiece or biosensor to the wireless headset 122, such as, for example, a mechanical fastener arrangement and/or use of other types of fasteners, such as hook/loop fasteners, clips, among others. Rails, guides, or like structures may also be used to specifically orient the releasably attached component with respect to the yolk, the ear tubes, or any other surface of the headset.

[0076] In certain implementations, recharging power may also be delivered to the chestpiece or biosensor via the releasable connection with the wireless headset 122. For example, the wireless headset 122 may include a wired connection port. Alternatively, the ear tubes or yolk may include exposed electrodes coupled to the headset power source. Attachment of, for example, wireless chestpiece 120 in a predetermined orientation may electrically couple the one or more electrodes on each component. This coupling may complete a circuit, thereby resulting in a transfer of current/energy to the wireless chestpiece. Alternatively, this circuit may also be used to charge the wireless headset 122, taking advantage of a battery or other power source on the biosensor. In certain implementations, the current charge or power state of the wireless headset may be communicated to the chestpiece or biosensor, and vice versa. Depending on the relative charge/remaining power, the wireless headset 122 may elect to receive or transmit power.

[0077] The wireless headset 122 may further include a pressure adjustment mechanism. The pressure adjustment mechanism allows a user to adjust the distance between ear tubes 132a and 132b. When pulled apart prior to insertion in a user’s ear, the ear tubes 132a, 132b are typically biased to return to the configuration depicted in FIG. 9. This ensures that ear tips 130a, 130b are acoustically coupled with a user’s ear drum for optimal delivery of body sounds. When coupled to a paired device, such bias may be unnecessary or uncomfortable for the user. Accordingly, the pressure adjustment mechanism can prevent full return of ear tubes 132a, 132b to the initial configuration. In certain implementations, the pressure adjustment mechanism includes a rack and pinion type system disposed in yolk 135. Additional adjustment mechanisms include adjustable springs or systems for varying the attraction between corresponding magnetic materials. In other implementations, the pressure adjustment mechanism includes a reel and lace system, similar to the system disclosed in US Publication No. 2006/0156517. These adjustable systems can allow for the user to specify the distance between the ear tubes 130a and 130b and the attendant pressure experienced in the ear canal during use.

[0078] In addition to the electronic stethoscope used in the telemedicine system 10 having alternative configurations, the
connection between the electronic stethoscopes may also have alternative configurations. For example, FIG. 10 is a diagrammatic view of a telemedicine system 150 according to an alternative embodiment. The telemedicine system 150 include a sensing electronic stethoscope 12a, a plurality of networked electronic stethoscopes 12b, 12c, ..., 12n, and a network interface or hub 152. The electronic stethoscopes 12a-12n communicate wirelessly with the network interface 152. The electronic stethoscopes 12a-12n may be configured substantially similarly and have substantially similar properties as electronic stethoscope 12 described above in FIG. 2. It will be appreciated that electronic stethoscope 12n is representative of the nth networked electronic stethoscope 12, and should not be construed as limiting or defining the number of networked electronic stethoscopes 12 connected to the network interface 152. In some embodiments, the network interface 152 is configured as a wearable, handheld, or portable device. In other suitable embodiments, the network interface is integrated with a wireless headset.

[0079] The network interface 152 is configured to establish a secure connection with the electronic stethoscopes 12a-12n. In some embodiments, the electronic stethoscopes 12a-12n are paired with the network interface 152 via a personal area network (PAN). One example of a PAN is a Bluetooth network, in which a pairing code is established on the network interface 152 and entered on each electronic stethoscope 12a-12n to securely connect to the network interface 152. In certain implementations, it may be acceptable to establish a single pairing at a time. When connected, the sensing electronic stethoscope 12a may be used to sense a patient's body sounds, while the networked electronic stethoscopes 12b-12n may be used to listen to the patient's sounds sensed by the sensing electronic stethoscope 12a in substantially real-time. In addition, other sounds, such as voice prompts, may be received on a sensor 38 or microphone 48 of one of the electronic stethoscopes 12a-12n and delivered to each of the networked electronic stethoscopes 12a-12n. In alternative embodiments, the electronic stethoscopes 12a-12n are networked directly to each other (i.e., without interfacing with the intermediate network interface 152).

[0080] In one example implementation, a teacher's electronic stethoscope 12 and the electronic stethoscopes 12 of one or more students may be networked via the network interface 152. The physician or a student may be selected to sense the patient's body sounds, while the networked users listen to the patient's sounds via their respective electronic stethoscopes 12. In addition, sounds stored in the teacher's electronic stethoscope 12 (or in another networked storage device) may be played back at substantially the same time to all networked electronic stethoscopes 12. The physician may also provide voice instructions or prompts via the sensor 38 or microphone 48 on the main housing 36 that are provided through the ear pieces of the students' electronic stethoscopes 12 at the same time as the sensed body sounds. Thus, if the physician's electronic stethoscope is being used to sense body sounds, the physician can demonstrate positioning and use of the electronic stethoscope 12a while the students listen on networked electronic stethoscopes 12b-12n. If a student's electronic stethoscope is being used to sense body sounds, the physician can provide instruction and guidance to the each of the students via the sensor 38 or microphone 48. In addition, each of the students with an electronic stethoscope 12 networked to the network interface 152 can take a turn sensing the body sounds while the physician provides individual guidance to them.

[0081] In other embodiments, networked scopes are connected to a computer or other external device (e.g., cell phone, PDA) as described above. The auscultation sounds and voice signals of a networked scope may be reproduced in substantial real-time by speakers connected to the computer or other external device. In some embodiments, body sounds may be downloaded from an electronic storage medium or other online database (e.g., website) to the computer or external device via a network connection and streamed to the networked stethoscopes and/or reproduced in substantial real time by speakers.

[0082] In another example implementation, a physician's wireless headset 122 and the electronic stethoscopes or biosensors of one or more students may be networked via the network interface. The physician or a student may be selected to sense the patient's body sounds, while the other networked users listen to the patient's body sounds via their respective electronic stethoscope headsets. In certain implementations, it may be preferred that the physician's wireless headset is paired with a single student's stethoscope or biosensor. The physician may also provide voice instructions or prompts via the microphone 132 that are provided through the ear pieces of the students' electronic stethoscopes 12 at the same time as the sensed body sounds. Thus, if the physician's electronic stethoscope is being used to sense body sounds, the physician can demonstrate positioning and use of his electronic stethoscope or biosensor while the students listen on networked electronic stethoscopes 12b-12n. If a student's electronic stethoscope is being used to sense body sounds, the physician can provide instruction and guidance to the each of the students via microphone 132. In addition, each of the students with an electronic stethoscope 12 networked to the network interface can take a turn sensing the body sounds while the physician provides individual guidance to them.

[0083] In summary, certain embodiments disclosed herein relate to a telemedicine system including a first electronic stethoscope including a housing configured for hand-held manipulation by a clinician relative to a patient, a transducer supported by the housing and configured to sense auscultation signals from the patient at a first location, and a headset coupled to the housing and configured to deliver audio corresponding to the auscultation signals through earpieces on the headset. The telemedicine system further includes a second electronic stethoscope including a housing, transducer, and headset substantially similar to the housing, transducer, and headset of the first electronic stethoscope. The first electronic stethoscope is configured to convert the auscultation signals to digital signals representative of the auscultation signals and to wirelessly transmit the digital signals to a second location via a secure digital network. The second electronic stethoscope is configured to receive the digital signals representative of the auscultation signals at the second location via the secure digital network, to convert the digital signals to audio corresponding to the auscultation signals, and to deliver the audio through earpieces on the headset of the second electronic stethoscope in substantially real time with the sensing of the auscultation sounds at the first location.

[0084] Various modifications and additions can be made to the exemplary embodiments discussed without departing from the scope of the present invention. For example, while the embodiments described above refer to particular features, the scope of this invention also includes embodiments having
different combinations of features and embodiments that do not include all of the described features. Accordingly, the scope of the present invention is intended to embrace all such alternatives, modifications, and variations as fall within
the scope of the claims, together with all equivalents thereof.

1. (canceled)

3-30. (canceled)

31. A bioacoustic sensor system comprising:
a housing configured for hand-held manipulation;
a transducer supported by the housing that senses auscultation signals at a first location;
a headset configured to deliver audio corresponding to the auscultation signals through earpieces on the headset; and

a processor disposed in the housing and configured to convert the auscultation signals to first digital signals representative of the auscultation signals and to wirelessly transmit the first digital signals from the bioacoustic sensor via a digital network to the headset in substantial real time with the sensing of the auscultation sounds at the first location; wherein the audio received by the headset corresponding to the auscultation signals is a digitally exact replica of the auscultation sounds sensed at the first location.

32. The bioacoustic sensor system of claim 31, wherein the transducer receives ambient audio at the first location, and wherein the processor is further configured to convert the ambient audio to second digital signals representative of the ambient audio and to wirelessly transmit the second digital signals with the first digital signals to the headset via the digital network.

33. The bioacoustic sensor system of claim 31, wherein the processor communicates over a secure personal area network via radio frequency signals.

34. The bioacoustic sensor system of claim 31, and further comprising:
a first antenna configured to wirelessly transmit the first digital signals from the electronic stethoscope via the secure digital connection.

35. The bioacoustic sensor system of claim 31, wherein the headset comprises a second antenna.

36. The bioacoustic sensor system of claim 31, wherein the processor is further configured to wirelessly receive signals from the headset via the digital network.

37. The bioacoustic sensor system of claim 36, wherein the signals comprise control signals.

38. The bioacoustic sensor system of claim 31, wherein the housing comprises a wireless chestpiece.

39. The bioacoustic sensor system of claim 31, wherein the headset includes a network interface.

40. The bioacoustic sensor system of claim 39, wherein the network interface includes a personal area network hub.

41. The bioacoustic sensor system of claim 39, wherein the network interface is configured to communicatively couple to a paired device selected from the group consisting of a personal computer, a tablet computer, a personal digital assistant, a cell phone, a smart phone, a digital music player, and combinations thereof.

42. The bioacoustic sensor system of claim 31, wherein the headset includes a pressure adjustment mechanism.

43. The bioacoustic sensor system of claim 31, wherein the housing is releasably retainable in the headset via a fastener.

44. The bioacoustic sensor system of claim 43, wherein the headset includes two ear tubes, and wherein the fastener is located on one or more of the ear tubes.

45. The bioacoustic sensor system of claim 43, wherein the headset comprises a yolk and a control housing coupled to the yolk, and wherein the fastener is located on the yolk, the control housing, or combinations thereof.

46. The bioacoustic sensor of claim 43, wherein the housing includes a power source, and wherein retaining the housing in the headset completes a circuit such that the power source can transfer electrical energy to headset.

47. The electronic stethoscope of claim 31, wherein the headset includes two ear tubes and a yolk including an interior volume, and at least a portion of at least one ear tube is movable between a first position and a second position, wherein at least a portion of the ear tube is received in the interior volume in the second position.

48. A telemmedicine system comprising:
a local bioacoustic sensor configured to sense auscultation signals from a patient and convert the signals to digital signals representative of auscultation signals;
a network interface connecting the local bioacoustic sensor to one or more additional electronic stethoscopes via a secure digital network, wherein each of the one or more additional electronic stethoscopes is configured to receive the digital signals representative of the auscultation signals via the secure digital network and to convert the digital signals to audio corresponding to the auscultation signals, wherein the audio is delivered through earpieces on a wireless headset coupled to at least one of the one or more additional electronic stethoscopes in substantial real time with the sensing of the auscultation sounds by the bioacoustic sensor;

wherein the network interface is a wearable personal area network hub, and wherein each of the local bioacoustic sensor and one or more additional electronic stethoscopes connect to the personal area network hub via a personal area network connection.

49. The telemmedicine system of claim 48, wherein the audio delivered to the wireless headset of at least one of the one or more additional electronic stethoscopes is a digitally exact replica of the auscultation sounds sensed by the local electronic stethoscope.

50. The telemmedicine system of claim 49, wherein the local bioacoustic sensor is further configured to wirelessly receive signals from the one or more additional electronic stethoscopes via the network interface.

51. The telemmedicine system of claim 48, wherein the personal area network hub is disposed in a wireless headset of an additional electronic stethoscope.

52. The telemmedicine system of claim 48, wherein the local bioacoustic sensor is communicatively coupled to a wireless headset and the personal area network hub is disposed in the local wireless headset.

53. A wireless headset for use in auscultation, the headset comprising:
a first ear tube and a second ear tube configured to deliver audio corresponding to acoustic signals through corresponding first and second earpieces on the headset

a yolk coupled to first and second ear tubes;
a communication system configured to receive digital signals from a bioacoustic sensor via a digital network in substantial real time, wherein the communication system includes a personal area network hub and wherein
the communication system and the bioacoustic sensor are connectable to the personal area network hub via a personal area network connection.

54. The wireless headset of claim 53, wherein the personal area network hub comprises a Bluetooth network.

55. The wireless headset of claim 53, wherein the personal area network hub comprises a wireless network access point.

56. The wireless headset of claim 53, and further comprising a pressure adjustment mechanism adjustable between a first position and a second position.

57. The wireless headset of claim 51, and wherein the communication interface is configured to communicatively couple to a paired device selected from the group consisting of a personal computer, a medical sensor configured for wireless communication, a tablet computer, a personal digital assistant, a cell phone, a smart phone, a digital music player, and combinations thereof.

58. A method for establishing communication between two devices, the method comprising:

providing a first device having a first communications system configured to establish a wireless communication link and a first sensor configured to generate an acceleration profile in response to movement of the first device;

providing a second device having a second communications system configured to establish a wireless communication link and a second sensor configured to generate an acceleration profile in response to movement of the second device;

moving the first device and the second device such that a first acceleration profile generated by the first sensor is at least similar to a second acceleration profile generated by the second sensor;

verifying the first acceleration profile matches the second acceleration profile; and

establishing a network connection between the first and second device.

59. The method of claim 58, wherein the first device is a headset and the second device is a bioacoustic sensor.

60. The method of claim 58, wherein moving the first device and the second device comprises grasping and moving both devices in concert.

61. The method of claim 58, wherein the first and second sensor comprise an accelerometer.

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