Stethoscopes: What Are We Hearing?

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This paper develops an objective methodology to test the audio quality of stethoscopes, classifies stethoscopes into five functional categories, and compares the audio performance of each of the five categories. These categories, based on the manufacturer’s recommended use, are basic assessment, cardiology, disposable, high-end cardiology, and physical assessment. The classification into categories is based on the intended performance of the stethoscopes as provided by the manufacturers. After developing the procedures and running more than 500 tests, the stethoscope with the least amount of loss over the spectrum was chosen from each of the five categories; the five were then compared to one another. Thirty-nine stethoscopes from 11 manufacturers were used in this study. The objective test methodology allows for side-by-side comparison of stethoscopes from various manufacturers that is independent of the manufacturer’s published test results. (Biomedical Instrumentation & Technology 2007;41:318-323)

The stethoscope is one of the most basic instruments used in diagnosing health problems and treating patients. Numerous models of stethoscopes exist on the market today, with prices ranging from a few dollars to well over $200. While many characteristics separate these stethoscopes, manufacturers market the high-end (higher-priced) stethoscopes as offering superior sound quality. The other characteristics that appear to contribute to price are comfort and prestige, which are subjective and, therefore, not included in this evaluation.

When manufacturers claim their stethoscope has superior sound quality (which may indicate a better instrument to diagnose patients), these claims are not based on any standard but instead are based on the manufacturer’s own evaluations. Without solid comparative evaluations, medical practitioners are left to continue purchasing stethoscopes strictly on the subjective recommendation given by their peers as to the quality of the instrument.

With no published standard existing for testing scopes, the authors interviewed staffs of the companies providing stethoscopes for testing. Each company indicated that they have in-house, propriety methods for evaluating stethoscope performance. There are several references to previous attempts to test the audio performance of stethoscopes.1–8 Many of the published works are related to training or evaluation of specific patient conditions.9–13 However, none of these studies offer a standard methodology or classification or provide an evaluation of performance for a wide range of stethoscopes.

Stethoscopes are used to transmit the sounds from a patient to the ears of the practitioner. The sound waves from the patient are transmitted to the scope’s bell or diaphragm of the chest piece via direct contact with the patient. The sounds are then transmitted down the tubing of the scope and into the binaural earpieces and into the ear. Stethoscopes are used primarily for assessing the subtleties of cardiac (heart) and pulmonary (lung) sounds and to determine the presence or absence of bowel sounds. Examples of frequency ranges for particular adult chest sounds include low heart sounds (including first, second, and third heart sounds) from 20 to 115 Hz; medium/high heart sounds (including systolic and diastolic murmurs) from 200 to 660 Hz; vesicular (normal) breathing from 150 to 1,000 Hz; bronchial breathing from 240 to 1,000 Hz; and crepitations (crackles) greater than or equal to 750 Hz.14 Wilkins et al. describe the many factors that affect the transmission of sound through body tissues, including changing tissue density, reflectance/absorbance, and travel distance.15

The human ear does not perceive different frequencies at the same loudness. The often-cited Flethcher-Munson curves show plots of equal loudness as a function of frequency, as shown in Figure 1.16 As a result, it is more difficult to hear sounds at the low and high extremes of the audible frequency range. With the onset of middle age, the maximum audible
frequency decreases to around 16 KHz (some adolescents have taken advantage of this by using mobile phone ring tones at 17 KHz so that school teachers are unaware of when their students’ phones ring in class). The age-related hearing loss does not present an auscultation problem for most clinicians because most chest sounds of interest are still well within the hearing range of mature adults.

Previous studies have indicated that stethoscope qualities such as tubing length and diameter, single versus double channel, type of chest piece, and materials may make a measurable difference in sound transmission. While this may be true, it is generally accepted that differences due to tubing length and diameter are minor enough that they are not detected by adults. Chest piece shape, angularity of the conducting channel, and especially fit of the ear pieces have greater bearing on the sound transmission differences in stethoscopes.2,6

Difficulties in Scope Testing

At first glance, testing stethoscopes appears straightforward. Input a sound at one end and measure the output at the other. The loss would then be calculated by dividing the decibel level signal strength of the output signal by the input signal. However, the stethoscope involves two human interfaces. The first is the interface between the patient and the diaphragm or bell of the scope. The bell chest piece is used to listen to the broadest range of physiologic sounds whereas the diaphragm functions as a low-pass filter to allow the listener to focus on lower frequency sounds. Many variables exist in this interface due to factors related to the patient and to the way the practitioner holds the end of the stethoscope (increasing hand contact with the chest piece effectively changes the chest piece mass and resonant behavior as well as the quality of contact with the chest surface). The other interface is the earpiece used by the practitioner, which again is subject to many variables including the shape of the practitioner’s ear canal and the placement of the earpiece in the ear. Ideally, testing would result in a measurement that could definitively indicate whether one stethoscope works better than another for all practitioners. However, due to these human factors one stethoscope might be the best fit for a particular practitioner even if the audio characteristics are suboptimal. Considering these complications, the testing presented in this study attempted to remove all variables related to these two interfaces so that claims of audio performance could be generically evaluated.

Several obstacles had to be considered:
- One factor that can be a source of error is audio leaks in the test setup. Losses in the system due to leaks contribute to as much as 10 to 15 dB. Most of the leaks in the system occur in the tubing of the stethoscopes or

### Table 1. Scopes tested per category.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Average Price</th>
<th>Models Tested</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic assessment/blood pressure</td>
<td>$12</td>
<td>4</td>
<td>$6 to $28</td>
</tr>
<tr>
<td>Cardiology</td>
<td>$121</td>
<td>7</td>
<td>$78 to $193</td>
</tr>
<tr>
<td>Disposable</td>
<td>$3</td>
<td>4</td>
<td>$3 to $5</td>
</tr>
<tr>
<td>High-end cardiology</td>
<td>$194</td>
<td>8</td>
<td>$135 to $250</td>
</tr>
<tr>
<td>Physical assessment</td>
<td>$44</td>
<td>16</td>
<td>$11 to $98</td>
</tr>
<tr>
<td>Average price all scopes</td>
<td>$81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range all scopes</td>
<td></td>
<td>$3 to $250</td>
<td></td>
</tr>
</tbody>
</table>
in earpieces that do not properly fit the test apparatus. The authors were able to develop a standard earpiece interface that provided a secure fit in order to keep setup losses consistent among all of the scopes.

• Ambient noise is also a problem. The authors reduced ambient noise levels significantly using an anechoic chamber (approximately 35 dB in noise reduction).

• A microphone used to capture the output sounds at the earpiece needs to have an input range down to 50 Hz, since some stethoscopes are required to respond to these frequencies. Many microphones will not respond at such low frequencies.

• The input signal into the bell or diaphragm of the stethoscope needs to range from 50 Hz to 3,000 Hz. Some companies use a sinusoidal sweep that moves from 50 Hz to 3,000 Hz over a few seconds as the input. The authors tested a 3-second sweep that resulted in suspicious spikes in the output signal even when the sweep was slowed down to 10 seconds. A pink noise input source was chosen with better results. Pink noise has equal energy at every octave and therefore produces a reasonably flat sound source.

Details
The following details indicate the methodology of the testing procedure, including the classification of scopes, the setup of the testing apparatus, and the validation procedures.

Classification of Scopes Into Categories
Manufacturers price and categorize stethoscopes based on the quality of the design and quality of the materials used. To help classify the various types of stethoscopes, the authors defined five categories so that every stethoscope would be compared with other stethoscopes in the same category. This categorization was based on the marketing data and the price that manufacturers provided for their stethoscopes. Table 1 shows the categories and the number of models tested from every category. (While the companies provided input as to the purpose of their stethoscope, categories were assigned by the authors, not the manufacturers.)

Stethoscopes also had other differences:

• Type of head used (diaphragm vs. bell or both): Most stethoscopes were general-purpose stethoscopes with both the diaphragm and the bell chest pieces attached on the end of the tubing. One stethoscope was a single-headed diaphragm, which could be converted into a bell or a diaphragm by varying the application of pressure on the head.

• Double vs. single tubing

• Hard vs. soft diaphragm scopes

• Disposable vs. nondisposable scopes.

Methodology: Setup
The setup consisted of a generic computer with a Sound Blaster sound card (Creative Labs, Milpitas, CA); an anechoic chamber with foam padding foundation (under the chamber); a small lab weight; a Sonitor (Almed Inc., San Marino, CA); an Electret microphone (Radio Shack, Fort Worth, TX); Cool Edit Pro Software (now Adobe Audition 2.0, San Jose, CA); and the stethoscope under test. Figure 2 shows the scope under test in the padded anechoic chamber.

A computer with a sound card was used to generate the source signal to the head of the scope as well as to capture sounds via a microphone from the scope earpiece. The computer used was a generic Pentium II 448 MHz with 64 MB RAM and had a single Creative Labs 16Bit-Dac 32-Voice Line Mic/Midi Interface ISA Waveffect Sound Blaster 16.

The line-out jack of the sound card was connected to the Sonitor, which sits inside the anechoic chamber. A Sonitor was used in amplifying and enhancing heart sounds and murmurs when played back over a computer. Sonitors are specifically designed for transmitting sounds directly from the computer sound card to the stethoscope and are used mostly for teaching. Sonitors are much better than a typical open paper/polymer speaker assembly as they play back low-frequency sounds and middiastolic
rumble of mitral stenosis better. The anechoic chamber was constructed from the guts of a video camera case that was 30 inches long by 12 inches wide and 8 inches tall (when closed). The case was lined with foam as shown in Figure 2. The entire chamber was placed on a sheet of 1.5-inch thick foam to reduce the ambient noise being transmitted from the surface the chamber rested on into the chamber itself.

The output signal transmitted into the Sonitor was a 30-Hz to 300-Hz pink noise source wave file that was created using Test Tone Generator (TTG) by Audiometer (Esseraudio, Holzgerlingen, Germany). The sound card output volume settings were manually adjusted to create a sound level similar in intensity to the heart sounds of a patient using a stethoscope.

The bell or diaphragm of the stethoscope under test was placed on the Sonitor and a small 100-g lab weight was placed on the head of the scope to mimic the pressure of the practitioner holding the stethoscope on the patient’s chest. (For the variable head Littmann Cardiology stethoscope a pressure of 500 g was applied to the chest piece to convert it into a diaphragm and the 100 g weight was used to convert it into a bell chest piece.)

The coupling of the microphone with the stethoscope consisted of hollow rubber tubing, one end of which was placed in a rubber sheath. The rubber sheath acted as a coupler for the microphone and the earpiece of the stethoscope. The microphone fit on one side of the coupler, which was inside the rubber tubing while the other side of the coupler was outside the rubber tubing and provided for a curved surface, which fit the stethoscope earpiece snugly. The section between the microphone and the earpiece had a volume of 1 cm³, which is the volume that can be expected in the coupling of a stethoscope earpiece to a human ear.

The microphone element (Electret 33-3028) had a factory-calibrated flat frequency response, shown in Figure 3, going from 0 KHz to 10 KHz and a sensitivity of 65 dB ± 4 dB (0 dB = 1 V/0.1 Pa @ 1 KHz). The frequency response of the microphone was tested and confirmed in the laboratory by running a frequency sweep going from 0 KHz to 10 KHz while measuring the output on the computer.

**Methodology: Testing**

The Cool Edit software on the computer played the pink noise source wave file while recording the output from the microphone at the same time. The recorded signals were saved as wave files using a naming convention that identified the model, scope (1–4), head type (bell or diaphragm), and test number. Each individual scope was tested four times. These wave files were later analyzed in bulk using scripts written in MATLAB (Mathworks, Natick, MA). The MATLAB scripts read in the data, performed a power spectral density analysis (PSD; used to find the power in each frequency range), and saved the output results. The results were then statistically analyzed to look for correlation using MATLAB.

**Methodology: Validation**

Thirty-nine stethoscopes were assessed. The pink noise

<table>
<thead>
<tr>
<th>Category</th>
<th>Mean Loss 600 Hz to 1,200 Hz (dB)</th>
<th>Mean Loss Full Spectrum (dB)</th>
</tr>
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<tbody>
<tr>
<td>Basic assessment/blood pressure</td>
<td>19.28</td>
<td>16.31</td>
</tr>
<tr>
<td>Cardiology</td>
<td>12.01</td>
<td>14.03</td>
</tr>
<tr>
<td>Disposable</td>
<td>15.42</td>
<td>14.85</td>
</tr>
<tr>
<td>High cardiology</td>
<td>15.08</td>
<td>13.71</td>
</tr>
<tr>
<td>Mean</td>
<td>15.92</td>
<td>17.19</td>
</tr>
<tr>
<td>Range</td>
<td>13.12 to 17.42</td>
<td>9.99 to 20.45</td>
</tr>
</tbody>
</table>

*Table 2. Average PSD characteristics.*
A source consistent from 0 Hz to 3,000 Hz was used as the input signal. To provide baseline test data, the microphone was placed on top of the Sonitor and the input signal was played, resulting in a baseline recording without the scope in the system as a reference signal to compare the stethoscopes under test.

After the baseline was recorded, each individual scope was tested four times by placing the scope in the system, running the test, removing the scope from the system, replacing the scope in the system, and rerunning the test. This process was repeated four times per scope, resulting in a total of 16 tests per scope model. The purpose of this process was to test the variations created in placing a scope in the system for testing since each setup required placement of the microphone on the earpiece and the scope head on the Sonitor with a weight. The results of these four tests were statistically compared (using correlation) to validate the test setup. Next, three other scopes of the same model were tested in this exact fashion, resulting in 16 tests run on each model of stethoscope.

Comparison of Stethoscopes
The authors wanted to make a determination if a stethoscope’s price and category indicated a true measure of the stethoscope’s ability to transmit the audio signal from the patient to the practitioner’s ear with a minimal amount of audio loss over the applicable frequency spectrum. To accomplish this task, the scope with the least amount of loss over the 3,000 Hz spectrum was chosen from each of the five categories. Loss was calculated by dividing the output signal strength by the input signal strength, where signal strength is in decibels. The overall loss over the spectrum was determined by calculating the area under the curve.

The five chosen scopes were then plotted to compare their PSD. Figure 4 shows the resulting PSD plots of the chosen scope from each category.

While there are significant differences between the scopes at specific frequencies, the overall results tell a different story. Table 2 shows a comparison of the stethoscopes using the mean loss in the 600 Hz to 1,200 Hz range (practitioners indicate this is the most significant range) and the loss over the entire 3,000 Hz spectrum. Since these figures are all losses, the smaller the absolute value of the number the better.

These results compare the best stethoscopes from each category and, therefore, do not indicate how a particular stethoscope might perform.

Conclusion
The purpose of the study was to develop an objective methodology to test audio quality of stethoscopes, classify stethoscopes into five functional categories, and compare the audio performance of stethoscopes in each of the five categories. Many stethoscopes are marketed as high end and/or high quality. Some are marketed indicating better performance for particular tasks, such as cardiology. The authors obtained more than 30 models of stethoscopes from various manufacturers and did a side-by-side comparison.

Based on the data, as demonstrated in Figure 4 and Table 2, the stethoscope grouping with the least amount
of loss over the spectrum was the physical assessment. The group with the highest amount of loss over the spectrum was the basic assessment, which we would expect to have significantly less loss than any disposable stethoscope. One would also expect any high-end cardiology stethoscope to have less loss than any other standard cardiology stethoscope—again, not the case for this sample (although it should be noted that the lowest loss individual bell and diaphragm models were from the high-end cardiology group). Manufacturers self-select the categorization of their products, and our results show the unreliability of this practice and the need for objective comparisons.

The initial results obtained show significant variation but do not correlate to category (and therefore price). The authors did not test other characteristics of the stethoscopes, such as comfort, aesthetics, or the perceived prestige of the practitioner using the stethoscope. Therefore, when a practitioner considers purchasing a stethoscope he or she must be aware that price and title may not be an indicator of the audio performance of the stethoscope. In fact, it may be just the opposite.

References

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