Validation of an effective, low cost, Free/open access 3D-printed stethoscope

Alexander Pavlosky1, Jennifer Glauche, Spencer Chambers1, Mahmoud Al-Alawi, Kliment Yanev, Tarek Loubani1,2,3,4\*

1 Faculty of Medicine, University of Western Ontario, London, Ontario, Canada.

2 Division of Emergency Medicine, Department of Medicine, University of Western Ontario, London, Ontario, Canada.

3 Division of Emergency Medicine, London Health Sciences Centre, London, Ontario, Canada

4 Division of Emergency Medicine, Al-Shifa Hospital, Gaza

\* Corresponding author

E-mail: Tarek.Loubani@lhsc.on.ca

# Abstract

The modern acoustic stethoscope is a powerful tool that clinicians use to detect subtle, pathological changes in cardiac, pulmonary and vascular sounds. Currently, brand-name stethoscopes such as the Littmann® Cardiology III are expensive clinical tools and are widely regarded as the gold standard despite limited innovations in design or fabrication in recent decades. Consequently, the high cost of these models serves as a barrier to clinicians practicing in low- and middle-income countries. In this publication, we describe the design and validation of a low-cost open-access (Free/Libre) 3D-printed stethoscope which is comparable to the Littmann® Cardiology III for use in low-access clinics.

# Introduction

Since its introduction in 1819, the acoustic stethoscope has been an integral part of clinical medicine and a powerful diagnostic tool in the hands of an astute clinician. Despite the lack of radical innovations in structure or design over recent decades, modern stethoscopes can be an expensive part of the physician’s armamentarium, often costing several hundred US dollars. The high cost of modern stethoscopes remains a significant barrier to physicians practicing in some developing countries, where few affordable high-quality options exist. Traditionally, the selection of a stethoscope often does not involve the acoustic properties of the model1 with most users selecting an expensive brand-name stethoscope such at the Littmann® Cardiology III – a model that is widely regarded as the field’s gold standard. However, previous studies which have compared stethoscope brands have concluded that cost does not correlate with better diaphragm sound quality at relevant frequencies, compared with lower-cost alternatives2,3.

Numerous groups have previously attempted to standardize methods to determine the efficacy of acoustic stethoscope models1,4–8, but currently no accepted standardized modality exists. Consequently, the performance of any acoustic stethoscope is little more than the manufacturer’s claim or the subjective opinion of the user. Some groups have attempted to objectively compare acoustic stethoscope models and currently two competing methods of measuring frequency response exist. The first method uses air coupling to transmit frequencies2,6 while the other uses a phantom to simulate vibrations of the chest wall7,9,10. These methods allow investigators to quantitatively compare the sensitivity of a stethoscope model compared with another.

In this article, we describe the construction and validation of a low cost, Free/open access 3D printed acoustic stethoscope - referred to here as the ‘Glia model’. The aim of the project is to give low budget health care systems affordable access to an effective stethoscope for a cost under $5 USD. To achieve this, we utilized 3D printing, a technology which is advancing rapidly and becoming increasingly inexpensive. The flexibility of 3D printing technology also allows users to augment our design to fit their own needs. We also attempt to make our validation methods accessible and low cost, allowing others to validate our design independently with ease.

# Methods

## ***Stethoscope design***

Design of the Glia model 3D printed stethoscopes was done using Free/Open Source Software (FOSS) so as to keep costs low and allow others easy access to examine and modify code. CrystalSCAD was used to create digital models of the stethoscope head, two ear tubes and an ear plug mold. OpenSCAD was used to create digital models of the Y-piece, stethoscope ring and spring (Fig 1A). Other accessory hardware is required, such as the plastic diaphragm, tubing, ear plugs (optional if the mold is not used) and steel spring (optional if the printed spring is not desired). These can be found in Table 1.

**Figure 1. Computer aided design and assembly of the 3D printed stethoscope.** Digital models of the 3D printed stethoscope parts are shown in Figure 1A. From left to right: the head, Y piece and ear tube are shown. An earplug mold design is also shown in Figure 1B. Each part was 3D printed in ABS, with the assembled stethoscope is shown in Figure 1C using the bill of materials listed in Table 1.

All print designs can be downloaded for free at https://github.com/GliaX

## ***Stethoscope printing and assembly***

Each part was printed on a commodity 3D printer using acrylonitrile butadiene styrene (ABS) with either 15% or 100% infill as indicated and 0.2mm layer height. A 40 cm silicone 12mm outer diameter (OD), 8mm inner diameter (ID) tube was attached between the stethoscope head and the larger bore of the Y piece. Two 9 cm silicone 6mm OD, 4mm ID tubes were attached between the smaller bore of the Y piece and the ear tubes. A diaphragm was cut from a Staples® brand PVC report cover (Swing-lock report cover, clear with black spine; UPC 718103160223) by turning a sharp caliper and creating a circular diaphragm with a 40mm diameter. This diaphragm was attached to the stethoscope head with a slotted rubber O-ring. However, in more recent models and due to difficulty finding such O-rings, we have replaced the O-ring with a printed ring. Spring steel was cut and crimped to form the ear tube spring. In more recent models, due to difficulty manipulating and acquiring spring steel, we have used a printed truss that has some spring properties.

Silicone was added to the ear plug molds (Fig 1B) as per manufacturer specifications and silicone ear plugs were attached to the ear tubes. The final construction can be seen in Fig 1C.

Costs in Table 1 were calculated using the density of ABS (1.03g/cm3) and the filament length, which is calculated by the printer driver. We assumed the price of 10 lbs (4.54 kg) of ABS pellets to be 31 USD.

***Acoustic transfer***

The frequency response of Glia model stethoscopes, compared with the Littmann® Cardiology III, was determined using an experimental setup modelled from a phantom-based frequency response setup previously described7. A latex balloon filled with 2L (2000g) of water was used as a phantom and each stethoscope was applied to the surface by hand. Phantom excitations were supplied by an external vibrating speaker at 86 Hz intervals between 0 and 5000 Hz (white noise) for 15 seconds. Three iterations of the Glia stethoscopes with variations in the output channel size and infill percentage were tested against the Littman Cardiology III. The output of each stethoscope was recorded by microphone for spectral analysis. The simplicity of this design was intended to allow other users to validate our design independently.

# Results

After many iterations, we successfully designed a working stethoscope, known as the Glia model (Fig 1), at a total cost of $2.83 USD. A bill of materials and cost breakdown can be found in Table 1.

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| --- | --- | --- |
| **Item** | **Dimensions** | **Cost (USD)** |
| Stethoscope head | 44.30mm x 62.45mm x 17.80mm | $0.206 |
| Stethoscope Y piece | 70.89mm x 29.94mm x 9.00mm | $0.09 |
| Stethoscope ear tube | 170.79mm x 83.62mm x 5.80mm | $0.07 |
| Stethoscope ring | r = 21mm, h = 7mm | $0.012 |
| Stethoscope spring | 91.25mm x 111.62mm x 15.05mm | $0.032 |
| Silicone tubing | 40 cm – 12mm OD, 8mm ID / 2x 9 cm – 6mm OD, 4 mm ID | $1.93 |
| Diaphragm | r = 20mm | $0.06 |
| Ear plugs with mold | n/a | $0.43 |
| **Total** | | **$2.83** |

**Table 1. Bill of materials for the Glia model stethoscope (100% infill)**

We compared three designs of the Glia stethoscope with varying channel sizes and infill percentages to the Littmann® Cardiology III, as described in the methods. At all frequencies tested, the Glia model performed similarly to the Cardiology III (Fig 2A). The performance of the 100% infill, 6mm channel size Glia model 2 is highlighted in Fig 2B and is comparable to the Littmann®, as demonstrated in the absolute difference curve.

**Figure 2. Calibration and comparison of 3D printed Glia model stethoscopes to the gold standard Littmann Cardiology III.** Stethoscope output responses were measured using the equipment setup described in the methods. Each stethoscope model recorded input sound at multiple frequencies and the change in amplitude between input and recorded sound was documented for each stethoscope (Figure 2A). Further comparison between the Glia Model 2 and the gold standard Littmann® Cardiology III is shown in Figure 3B with the absolute Δ magnitude plotted above (Figure 2B).

# Discussion

The stethoscope is one of the most widely used instruments in modern medicine, allowing clinicians to detect subtle changes in heart, lung and vascular sounds. Despite a lack of major innovation in design or fabrication since Dr. Littmann patented his stethoscope in 1963, the acoustic stethoscope remains an expensive piece of equipment that creates a cost barrier for physicians practicing in developing nations. This study aims to create a high quality acoustic stethoscope at a cost under 5 USD.

The quality and intensity of the sound reaching the earpiece from the diaphragm is dependent on nearly every piece of the stethoscope as well as the physiology of the user. These variables have been previously well summarized2 and include the size and volume of the bell6,11; hardness of the inner cavity of the bell12; improperly fitted components allowing air leaks and loss of sound11; the thickness, size and tautness of the diaphragm and the interior smoothness, rigidity, length and diameter of the tubing13,14. Additional user related factors include improperly fitted ear pieces that allow air exchange3,11,14,15; anatomical variations of the auditory canal of the user15; background noise16 and training17. Many of these variables needed to be considered when designing the Glia model stethoscope, particularly physical properties such as channel diameter through the 3D printed parts and infill percentage, which ultimately determines the density and hardness of the parts.

As previously mentioned, no standard method of determining the acoustic response of stethoscope models currently exists. Previous studies have attempted to objectively quantify stethoscope efficacy6,7,9,10 and previous comparisons between brands indicate that no significant correlation between cost and quality exists2,3. However, there may be some subjective decrease in efficacy when using low-quality disposable stethoscopes17. Using a phantom-based method, we show here that the Glia model stethoscope, at a cost of 2.83 USD, is comparable to the Littmann® Cardiology III across a range of spectral frequencies from 86 Hz to 5000 Hz, making it a low-cost, suitable alternative to those who cannot access or afford a high cost model. Ultimately, however, the usefulness of any stethoscope is dependent on user preference and so we encourage those with access to a 3D printer to build and test our model independently.

The Glia model stethoscope is a class I medical device according to Health Canada and the FDA. In Canada, a non-profit company was incorporated to manufacture stethoscopes and has received a Medical Device Establishment Licence from Health Canada. The stethoscope is in clinical use in London, Canada at the London Health Sciences Centre. It has also been trialed and is gradually being introduced in the Gaza strip, an area with extremely limited access to medical devices. Hospitals in Gaza are self-sufficient producers of these stethoscopes.

Future plans include expanding access by providing validated models of other pieces of medical equipment, including pulse oximeters and ECG machines, allowing health institutions to sustainably produce affordable, high quality equipment for many clinicians.

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