A Silicone Human Head Model for Testing Acoustic Properties of the Upper Airway

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***Abstract*— The purpose of this project is to create an actual-size, anatomically accurate human head model that contains a void for the upper airway. The model is intended to be used for studying the acoustic properties of the breathing sound. The model was constructed with silicone rubber that has acoustic properties similar to those of soft tissues. The main challenge of the project was to construct the model with a single, homogeneous piece of silicone, which is necessary to avoid any interface affecting the sound transmission. The model included the head, portion of the neck containing the suprasternal notch, a functioning airway with nasal and oral passageways, sinuses, and the trachea. A technique developed in this study was the development of an airway model made of gelatin. The gelatin model occupied the space in the head model mold when silicone rubber was poured. The gelatin was later removed by boiling the model in water to leave the void of the airway inside the model.**

Keywords- anatomical head model; upper airway; silicone rubber; gelatin; breathing sound

I. Introduction

A head model containing the upper airway should be useful for studying the acoustics of the breathing sound. Specifically, the model could be used to investigate the frequency spectra of sounds generated by air flows through the upper airway and the sources of certain acoustic signals such as the larynx and the root of the tongue where obstructive sleep apnea usually occurs. However, such a head model is not readily available. The model needs not only to have a relatively accurate representation of the anatomy but also to possess the properties of sound wave propagation similar to those in the human body.

Airway models made of silicone rubber were constructed in the past for studying nasal and tracheal airflows [1], [2] and aerosol particle distributions [3]. Because those studies were confined to only airflows within the airway, those models could be built by splicing different parts together. In the present study, we are interested in not only the airflows but also the acoustic signals generated by the airflows and how they propagate to the outer surface. Our model cannot be constructed by splicing two or more parts together. Otherwise, the interfaces where different parts are joined would create artificial barriers to the sound propagation. The long-term goal of this study is to develop a mock airway model that produces acoustic signals similar to the breathing sounds. The specific goal of this study is to solve the technical challenge of creating a head model with an embedded airway from a single piece of homogeneous silicon rubber.

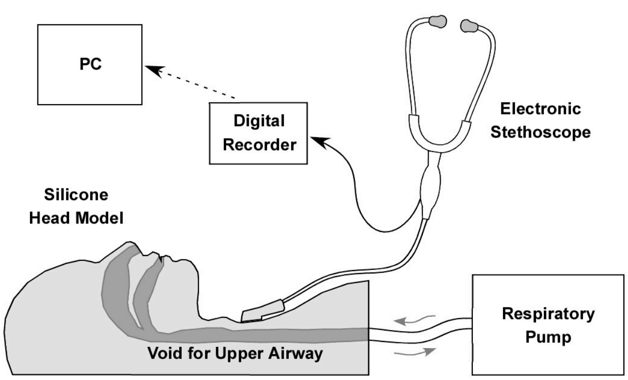

Figure 1. Schematic diagram of a mock airway model that produces acoustic signals similar to the breathing sounds

	Sound velocity (m/s)	Density (g/cm^3)
Soft tissue	1540	1.02
Silicone rubber	948	1.25
Soft rubber	1480	1.1

Table 1. Comparison of sound velocity and density among soft tissue, silicone rubber, and soft rubber.

II. Methodology

A. Overall Instrumentation

As shown in Fig. 1, a mock airway model consists of a head model with an embedded airway. A respiratory pump supplies airflows in and out of the airway. An electronic stethoscope is used to monitor the sound generated by airflows. The acoustic signals are digitized and stored in a hand-held digital recorder. The data are uploaded offline to a personal computer for further analyses.

The material for the head model should have acoustic properties similar to those of the soft tissue. Table 1 provides a comparison of sound velocity and density of three materials: soft tissue, silicone rubber and soft rubber. Although soft rubber is closer to soft tissue, silicone rubber was chosen because of its ease of use and environmental friendliness. Silicone rubber has low toxicity, low chemical reactivity, low thermal conductivity, and no emission of hazardous fumes.

B. The Outer Mold

As shown in Fig. 2, the head model is to be molded as a single piece of silicone rubber. The head model contains a void representing the airway. The back side of the head model is flattened such that it can be laid down stably on a

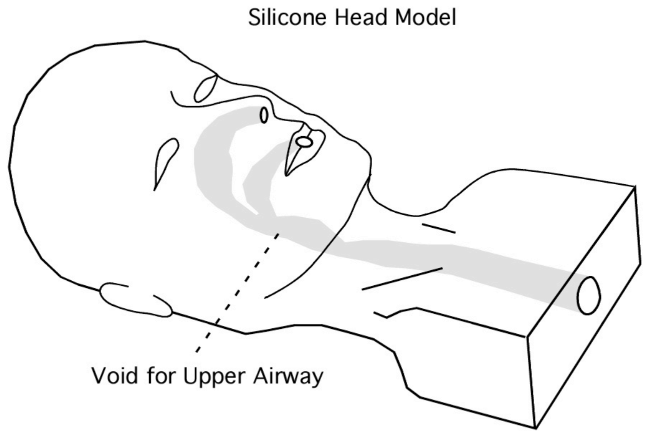

Figure 2. Schematic diagram of the head model containing the airway.

flat surface. A commercially available head mannequin was used to build the head model. This mannequin spans from the breast-bone of the human body upwards. An outer negative mold of the head was created by dipping the mannequin face-first into a plastic container filled with the plaster of Paris water mixture. Once the plaster dried, the mannequin was removed. The plaster mold was sealed with an acrylic based sealant.

C. *The Void*

Using the oven-bake clay a negative mold for the airway is created. The airway included the trachea, the mouth and nasal chambers. The airway mold was split sagittally into two equal halves. One cardboard stencil of the trachea was used to trace the trachea and sinuses. The oven-bake clay was carved to form a trachea and sinuses of the nasal and esophageal passageways.

D. *The Inner "Gelatin" Mold*

The void needs to be occupied by a solid material when silicone rubber is poured into the outer mold. The void is of an irregular shape. Thus, the challenge is how to remove the material in the void after the silicone rubber is hardened. Agar gelatin was chosen as the material for filling the void, which is much more sturdy and durable than fruit gelatin. When boiled in water, agar gelatin is liquefied and can be easily removed. The clay mold for the void was lubricated with Vaseline. The dissolved agar gelatin was poured into the clay mold. The gelatin needed about an hour to harden at room temperature, and was then removed by separating the two halves of the clay mold.

E. *Silicon Head*

The agar gelatin airway model was placed inside the outer mold. The gelatin was anchored down to the hole in the mouth and the tracheal hole to prevent it from floating to the top. The silicone rubber mixture was prepared and placed inside a vacuum tank for removing air bubbles. The silicone rubber mixture was poured into the mold and allowed to set. After 24 hours the silicon rubber was removed from the plaster outer mold and boiled in water. The gelatin was dissolved and removed from the trachea, sinuses and mouth.

III. Results

As shown in Fig. 3, the head model containing an airway void was successfully produced from a single piece of homogeneous silicone rubber. The plaster outer mold for the head and the clay mold for the gelatin airway were intact and can be reused for pouring additional units.

Figure 3. The silicone-rubber head model that has a void inside representing the tracheal, mouth and nasal chambers.

IV. Discussion

This study has demonstrated a technique to create a silicone-rubber head model containing an airway. The away model is made of agar gelatin, allowing for easy removal to create a void inside the head model. For future work, the head model will continuously be improved in conjunction with the acoustic measurements. The long-term goal is to create a mock airway model for studying the acoustics of the breathing sound.

Acknowledgment

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