ICVPB 2020

12th International Conference on Voice Physiology and Biomechanics
March 18-20, 2020, Grenoble, France

Fabrication of synthetic, multi-material vocal fold models via embedded 3D printing

Taylor E. Greenwood, Scott L. Thomson*

Department of Mechanical Engineering, Brigham Young University, Provo, Utah, USA

Keywords: synthetic vocal fold models; 3D printing; embedded printing

Introduction

Synthetic, self-oscillating vocal fold (VF) models are physical models made from silicone rubber whose life-like vibration is induced and sustained by fluid flow. Among synthetic models, multi-layer models have been found to reasonably replicate the vibratory characteristics of human VFs [1]. Multi-layer models consist of multiple layers of silicone rubber, analogous to tissue layers within human VFs, where geometry and stiffness of each layer contribute to model performance. During fabrication, each layer is cast around previous layers in a multi-step process using a coordinated set of negative molds.

The development and use of multi-layer models, however, are limited because the iterative casting process is challenging and time intensive. A change in model geometry, for instance, requires a new set of positive and negative molds. Furthermore, fabrication yield is low because the interconnected nature of the material layers means an error in any one step often requires the casting process to be restarted.

The purpose of this study was to extend a recently-developed 3D printing process to the fabrication of multi-layer VF models. In addition to avoiding some of the challenges associated with the iterative casting process, we hypothesized that 3D printing would be faster, more material efficient, and potentially more versatile than casting, especially when creating models with new geometries.

Methods

An embedded 3D (EMB3D) [2] printing process was selected and adapted for fabricating the "EPI" VF model originally developed by Murray and Thomson [1,3]. This model consists of four material layers representing the body, ligament, superficial lamina propria (SLP), and epithelium. EMB3D printing is a hybrid of casting and 3D printing processes. In this method, a reservoir of the desired shape is filled with a curable gel-like material ("support matrix"). Shapes of different materials are then "embedded" within the support matrix by printing secondary materials throughout the matrix. In the present work we fabricated the EPI model by 3D printing the ligament and body layers within a single negative SLP mold as shown in Fig. 1.

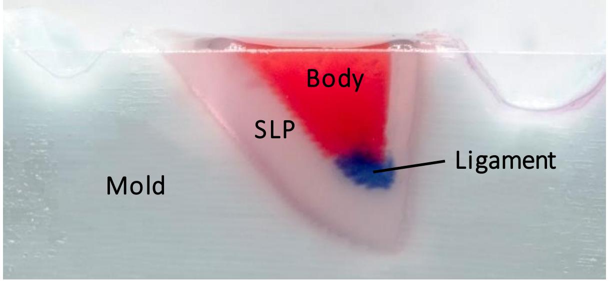

Figure 1: Side view image of an embedded 3D-printed VF model before demolding. The cavity in which the VF model is here seen was first filled with uncured SLP material. The ligament and body layers were then sequentially printed within the uncured material.

Results and Discussion

In this presentation, we will describe vibration testing performed on the printed models in hemilarynx and full larynx configurations to collect vibration frequency, onset pressure, amplitude, and flow rate data. Analyses of the geometry and material properties of the printed layers to determine the accuracy of 3D printing in replicating the desired model parameters will be presented. The results of vibration tests to compare frequency, onset pressure, amplitude, and flow rate data of 3D printed models to traditional cast models will then be shown and discussed. Vibration patterns of printed multi-material models characterized using high-speed imaging will also be presented. The results will be used to demonstrate the overall effectiveness and efficiency of embedded 3D printing as an approach for fabricating multi-material VF models. It is anticipated that this process will accelerate the development of multi-material VF models and expand the ability of synthetic VF models to investigate the effects of interior geometry and stiffness on VF vibration.

Acknowledgements

This work was supported by grant number R01 DC005788 from the National Institute on Deafness and Other Communication Disorders (NIDCD) of the National Institutes of Health. Its content is solely the responsibility of the authors.

References

[1] Murray and Thomson, J Acoust Soc Am, 132:3428-3438, 2012.
[2] Wehner et al., Nature, 536:451-455, 2016.
[3] Murray and Thomson, J Visualized Exp, 58, 2011.

*thomson@byu.edu