Design and optimization of patient-specific, pediatric laryngoscopes

###### R. Sims1, M. Boutelle1, J. Inziello1, and F. Lobo1\*

1 PD3D Lab, University of Central Florida, Orlando, United States of America

\* Corresponding author, email: [jstubbs@ist.ucf.edu](mailto:jstubbs@ist.ucf.edu)

Abstract: Place a brief summary of your work here. Do not use more than 100 words. 3D printing is of outstanding importance in medical engineering and has been growing continuously in recent years. From prostheses and soft implants to matrices for tissue engineering, additive manufacturing has decisive advantages for medicine. The scientific conference AMMM 2019 brings together engineers, scientists and technicians with physicians and entrepreneurs to discuss the latest achievements in 3D printing development for medicine.

# I. Introduction

Originally developed for otolaryngologists to inspect vocal cords, laryngoscopes have undergone continuous modifications since their inception, eventually finding a place in anesthesiology. In 1911, Dr. Chevalier Jackson published “The Technique of Insertion of Endotracheal Insufflation Tubes.” In this publication, Dr. Jackson disclosed designs for a laryngoscope featuring a removable floor. The feature allowed for the insertion of an endotracheal tube (ETT) [1]. Dr. Henry Janeway, an anesthesiologist from New York, USA, developed a blade with a central notch allowing for the insertion of an ETT. Janeway’s design featured a battery powered, distal light source allowing for optimized viewing conditions [1]. Modern laryngoscopes, such as the Macintosh and Miller, began manufacturing in the early 1940’s. The Macintosh’s continuous curved blade allots more room in the oropharynx for successful passage of the ETT, in addition to inducing less trauma to the upper airway and upper teeth. The Miller’s straight blade design, with curved distal tip, provides an improved view of the glottis [2].

In the last few decades, laryngoscope design changes have focused on addressing challenging airways. Most modern laryngoscopes, such as the McGrath, Glidescope and Airtraq, feature integrated optics and video screens. Additionally, the three brands also feature variable-size, single-use (disposable) blades. Blade sizes are distributed unevenly across adults (3-4 sizes), pediatrics (one size), and neonates (one size). Sizes match a range of ETT sizes (2.5-3.5 for neonate, and 4.0-5.5 for pediatrics) [3].

As the industry moves in the direction of single-use medical devices, there is potential to shift from size groups to patient-specific blades. This is of particular importance to pediatric and neonatal cases, were size options are limited. Difficulties with intubation represent the main cause of pediatric, anesthesia-related morbidities and mortality [4]. Even in scenarios where difficult intubations are expected, anesthesiologists know to have “all the equipment to hand,” which translates into a clutter of devices and cost inefficiencies [5]. Patient-specific blades would ensure readiness in the case of normal and abnormal airways – the latter representing an issue not yet addressed by current commercial solutions.

The development of patient specific devices requires the integration of advanced reconstruction, design, and manufacturing technologies. Our team has consolidated the majority of the design process into a single Houdini-based program (SideFx, \_\_, \_\_). The program takes patient-specific CT DICOM stacks and generates a 3D solid model of a patient-specific laryngoscope blade (Figure 1).

Figure 1: Houdini Program Flowchart

# II. Material and methods

## II.I. Patient Data

The raw patient data should be geometry of the tissue and bone in the patient, leaving the airway of the patient hollow. In most segmentation software, this is a simple task, and can even be done in Houdini, using our custom segmentation software, to avoid using different software.

## II.II. Patient Data

We used Houdini FX, a VFX software traditionally used in the film and games industries to create a process for rapidly segmenting airways from patient geometry, finding the average path through that airway, then using that data to procedurally design a laryngoscope that is sized to perfectly fit the patient it has been designed for. This process starts with importing patient data, which can be created using any software (including Houdini with our customized DICOM toolset built for Houdini). Next, the data can be segmented inside of Houdini to isolate the negative space of the patient’s airway. After that a solver is ran to determine the path and width of the airway, before finally extruding the tool along the toolpath created from the patient data, and fabricating the new device using 3D printing technologies. Figure 1, below, shows this process broken into several distinct parts, for importing patient data, refining patient data, finding a close bounding shape, segmenting the airway from the rest of the patient data, finding the center line, which can be exported for use in other cad software, or applied to the tool profile in Houdini to create a device.

## II.III. Segmentation

The segmentation step involves creating a shell around the base geometry, using a shrink-wrap operation, and then using a subtraction operation to cut the source patient geometry from the shell geometry. This will leave the airway, and any other empty space inside of the patient data geometry, allowing easy removal of the disconnected parts, leaving only the negative space of the airway.

## II.IV. Pathfinding

After the airway volume has been segmented, there are two options for finding its center path, one being the use of a modified space colonization algorithm, and the other using Houdini’s native find shortest path node.

The space colonization method, takes an input point near the front of the volume, where the mouth would be, and using a point cloud defined inside of the airway’s volume to organically grow a path through the airway, which can be averaged to find a close approximation of the curvature of the airway.

The other option is to select a group of points at the mouth, and another group at the end of the airway, and to use find the shortest path between the two groups using a point cloud similar to the one used for space colonization method, and averaging the paths to find a centerline.

## II.V. Part Design

Using the airway path designed above, you can extrude and loft a tool shape along this path to create a laryngoscope that will follow the path of the airway, and can be easily and quickly customized to any patient.

## II.VI. Fabrication

Since this part was designed in a digital space, it can be easily exported for creation on a 3D printer. This methodology would allow for the rapid creation of one-time-use medical devices that could be designed on an as needed basis for patients as they enter a hospital with minimal wait time.

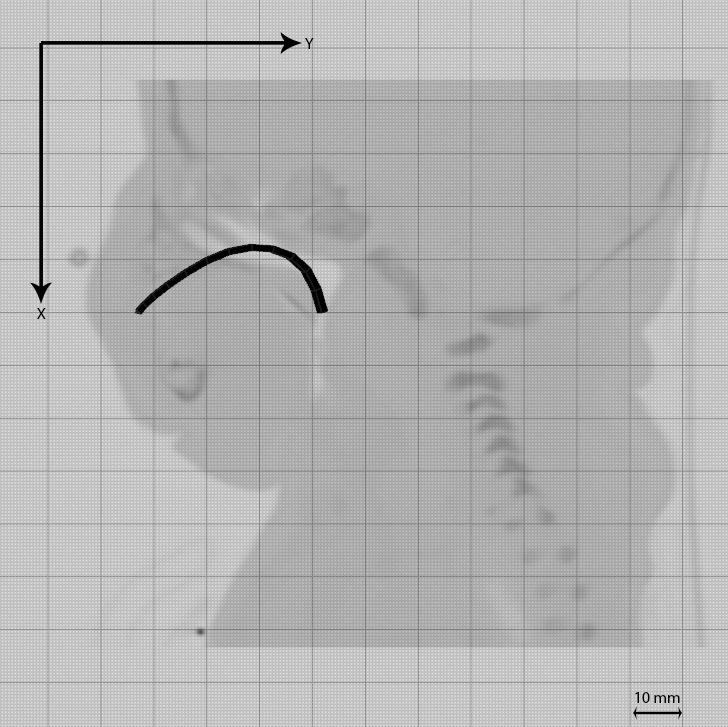
# III. Results and discussion

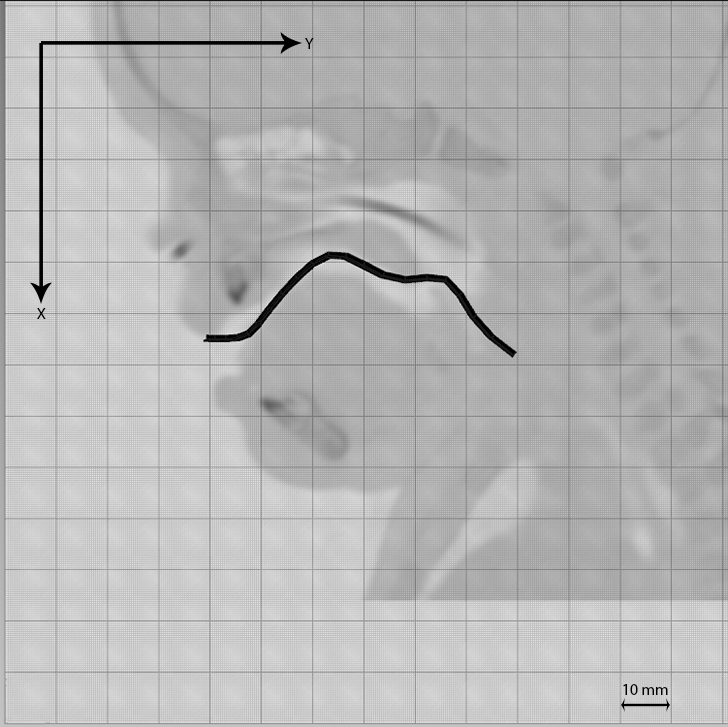
Table 1: Values used to achieve airway curvature

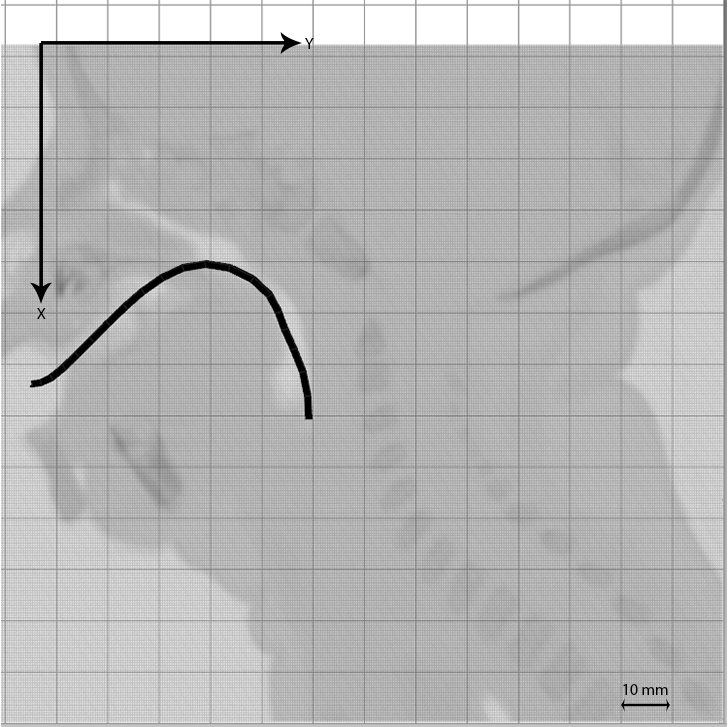
|  |  |  |  |
| --- | --- | --- | --- |
| **Parameter** | **Unit** | **Value** | **Standard Deviation** |
|  |  |  |  |
| Voxel Resolution1 | Millimeters | 0.80 | 0.33 |
| Erosion Amount | Millimeters | 2.4 | 0.0 |
| Dilation Amount | Millimeters | 8.0 | 0.0 |
| Ray Scale | N/A | 1.0 | 0.0 |
| Point Separation2 | Millimeters | 3.00 | 0.94 |
| Frames3 | N/A | 10 | 1.88 |

1 Voxel resolution had to be decreased for some scans in order to maintain enough detail to portray the airway, this change is mainly cosmetic and doesn’t affect other calculations.

2 Similarly to the above note, this number had to be changed in order to endure there were enough points scattered in parts of the volume that were otherwise too small.

3 depending on the length of the airway, more or less steps in the solving step may be required.





# IV. Conclusions

Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

### Acknowledgments

##### The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression, “One of us (R. B. G.) thanks . . .” Instead, try “R. B. G. thanks”.

### Author’s statement

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