Design and optimization of patient-specific, pediatric laryngoscopes

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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, ON, CA). 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

De-identified or anonymized CT DICOM datasets from three (3) pediatric cases were obtained from Nemours Children’s Hospital (Lake Nona, FL, USA). In addition to age, the only additional information retrieved were notes solely related to findings that could have an effect on the patient’s airway.

The first patient, 18 months old, did not present any lesions or abnormalities affecting the airway. The second patient, 2 months old, presented a well-defined ovoid lesion measuring approximately 3.0 cm x 3.6 cm x 2.8 cm. The lesion was situated deep to the left lobe of thyroid gland and medial to the left common carotid artery and internal jugular vein. It extends medially in the prevertebral space across the midline; anteriorly the lesion displaces the left lobe of the thyroid. The resulting airway is deviated to the right side from the effect of the lesion. The third patient, also 18 months old, presented a lesion on the right side of the neck. The lesion compromised the patient’s oral cavity, oropharynx, and nasopharynx, resulting in the slight narrowing of the airway.

## II.II. Segmentation

Relying on Houdini’s Python 2.x compatibility and Pydicom [ref], our team built custom functions (or nodes in Houdini) to: (1) Import CT DICOM dataset into a voxel (3D pixel) volume, (2) Map the associated Hounsfield data to a [-1, 1] density scale, and (3) Pad boundary voxel data to generate a closed geometry.

## II.II. Shrink-Wrapping

Through a series of voxel-based erosions and dilations, an enlarged copy of the segmented geometry was used extract the patient’s airway through a Boolean subtraction.

## II.III. 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

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.

## II.IV. 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.V. Fabrication Readiness

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

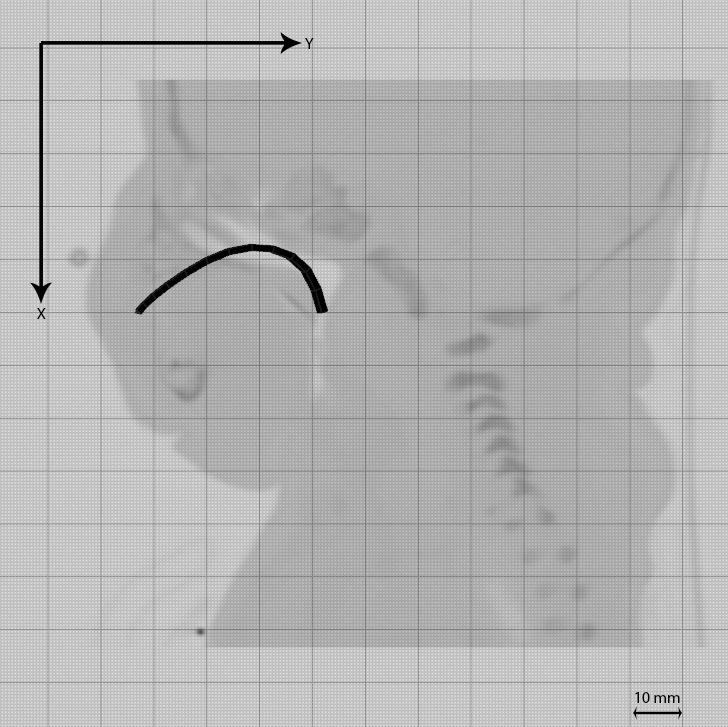
Table 1: Values used to achieve airway curvature

|  |  |  |  |
| --- | --- | --- | --- |
| **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 |

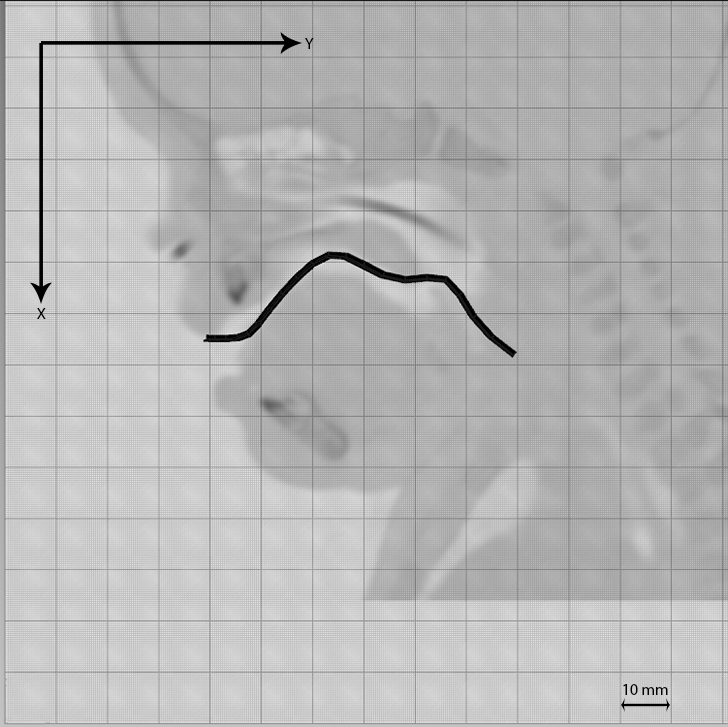
1 Using a fixed threshold value of 0.20 (or 200 HU), a closed geometry

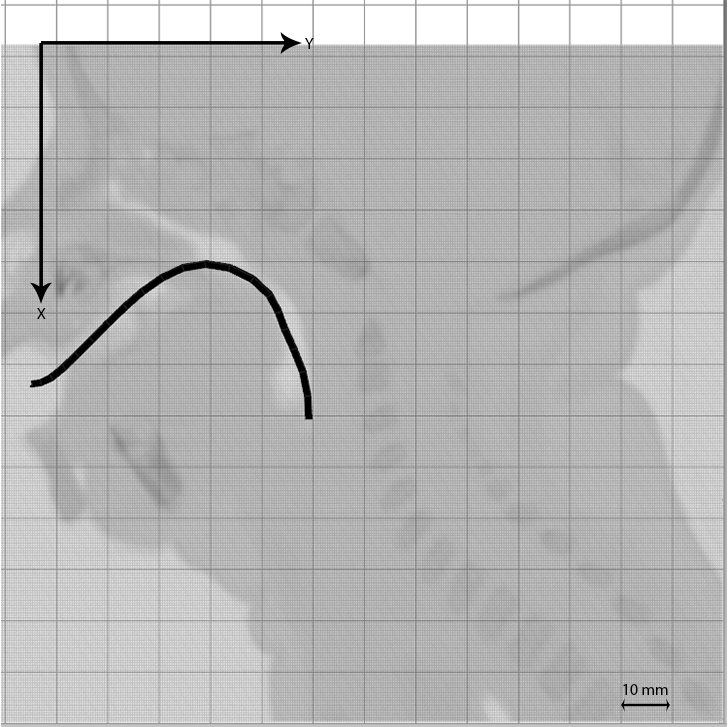
Voxel resolution had to be decreased for some scans in order to maintain enough detail to portray the airway, this change is mainly cosmetic and doesn’t affect other calculations.

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.

Talk about why going through positive anatomy instead of negative Anatomy?!?!?!?





# 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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#### References

[1] M. Weiss and T. Engelhardt, "Proposal for the management of the unexpected difficult pediatric airway," *Pediatric Anesthesia,* no. 20, pp. 454-464, 2010.

[2] R. W. M. Walker and J. Ellwood, "The Management of difficult intubation in children," *Pediatric Anesthesia,* no. 19, pp. 77-87, 2009.