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

Physicians have utilized specialized tools to examine vocal cords since the mid 1700’s. Originally developed for otolaryngologists to view the vocal cords, laryngoscopes have undergone continuous modifications since their inception, eventually finding a place in anesthesiology. During the mid 1850’s, Manuel Garcia was the first individual to view a functioning glottis in its entirety. It wasn’t until the turn of the 20th century that laryngoscope advancements were specifically applied to anesthesiology. Chevalier Jackson published “The Technique of Insertion of Endotracheal Insufflation Tubes” where he disclosed new designs for direct laryngoscopy. The laryngoscope blade featured a removable floor, allowing for the insertion of an endotracheal tube (ETT) [1]. Coetaneous with this development, Henry Janeway, an anesthesiologist from New York, USA, developed a blade with a central notch allowing for the insertion of an ETT which he published in “Intratracheal Anesthesia from the Standpoint of the Nose, Throat and Oral Surgeon with a Description of a New Instrument for Catheterizing the Trachea”. This design featured a battery powered, distal light source allowing for optimized viewing conditions [1]. Modern laryngoscope blades such as the Macintosh and Miller blades, began manufacturing in the early 1940’s and quickly became the new standard for laryngoscopy.

Macintosh blades tend to be preferred by healthcare professionals working with normal airways. The 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 [2]. The Miller blade with a straight design with curved distal tip, provides an improved view of the glottis. This blade design is preferred for patients with a long floppy epiglottis or anterior larynx, such as pediatrics and neonates [2]. Video laryngoscopes are arguably the most modern advancement to laryngoscopy. The integration of optics provides visualization of anatomical landmarks in attempt to ease patient intubation. The most remarkable improvement is with regards to difficult airways [3].

The most notable modern laryngoscopes include the McGrath, Glidescope and Airtraq. All three companies integrate the use of optics and have variable blade sizes. Blades are single use, disposable and have proprietary shapes. Airtraq is the only instance of fully disposable optic and blade. Sizes include three to four adult sizes, one pediatric size and one neonate size. All blade variations are fit to ETT sizes (2.5-3.5 for neonate, and 4.0-5.5 for pediatrics) [3]. Even though there are specific neonate and pediatric sizes blades, the shape is still proprietary, not providing any variation for abnormal anatomy or airway malformations. 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].

The design of patient-specific devices requires several steps…

# II. Material and methods

## II.I. Patient Data

Our data set is collected from Nemours Children’s Hospital (Lake Nona, FL – USA). Patient 1 (0002) is an 18-month-old female that represents a patent airway of normal size and location. The two remaining patients represent anatomical abnormalities that result in a difficult airway. Patient 2 (0012) is a 2-month-old male that has a well-defined ovoid lesion measuring approximately 3.0 x 3.6 x 2.8 cm. The lesion is situated on the left side of the neck, 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 mass. Patient 3 (0005) is an 18-month-old female with a very large infantile fibrosarcoma in the right side of the neck. The tumor shows multifocal hemorrhage and necrosis, involving skin and soft tissues with vascular invasion by the tumor present. The mass encroaches on oral cavity, oropharynx, nasopharynx resulting in the airway being slightly narrowed.

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.

Figure 1: Process and Program Diagram

## 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: Results

|  |  |  |
| --- | --- | --- |
| **Segmentation** | | |
| **Thresholding** | | |
| **Patient** | **Value** | **Unit** |
| 1 | 24, Bold, Calibri | Title |
| 2 | 12, Bold, Calibri | Authors |
| 3 | 12, Italic, Calibri | Affiliation |
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# 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

##### Research funding: The author state no funding involved. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors’ institutional review board or equivalent committee.

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