Comparing pediatric airway variability to standard laryngoscope sizes for 3D printing patient specific blades.

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Abstract: Commercially available pediatric laryngoscope blades have limited variability in shape and sizes. Difficult airway intubations may require physicians to improvise in their selection of a patient's blade size and could potentially lead to physical trauma and complications. With advancements in three-dimensional (3D) imaging, modeling, and printing, we are introducing a method for the design and fabrication of patient specific pediatric laryngoscopes at the point of care and comparing our methods to current industry standards.

I. Introduction

Pediatric laryngoscope blade size options are limited. The lack of variability in blade size is associated with difficulties in pediatric intubation for both abnormal and normal airways which cause anesthesia related issues and deaths [1]. Typical laryngoscopes feature three pediatric sizes classified by patient weight [2].

Previously, our team introduced a semi-automated method for the design and 3D printing of patient specific laryngoscope blades as means to address the shortage of sizes [3]. We have modeled fifteen (15) patient specific blades and compared them to the industry standard to further highlight the disparity in pediatric airway intubation.

II. Material and methods

II.I. Pediatric Patient Data

De-identified computed tomography (CT) datasets from fifteen (15) cases were obtained from Nemours Children's Hospital (Lake Nona, FL, USA). Age, weight, and height of these patients was obtained, when available, with the goal of establishing correlations with the patient's airway.

II.II. Procedural Method

In 2019, we introduced a procedural method for: (1) reconstructing patient-specific anatomy from a CT dataset, (2) extracting or isolating the patient's airway, and (3) creating build paths for fabricating a laryngoscope blade specific to the patient's airway [3].

Our method uses Pydicom, a Python library for manipulating digital medical images [4], to generate 3D patient-specific anatomical reconstructions. The airway anatomy is isolated with a method described as shrink wrapping. In this step, a copy of the 3D patient-specific reconstruction is dilated until all the internal structures are filled. The dilated volume is then wrapped onto the original reconstruction, which is subtracted from the shrink-wrapped volume, resulting in an isolated volume of the patient's airway.

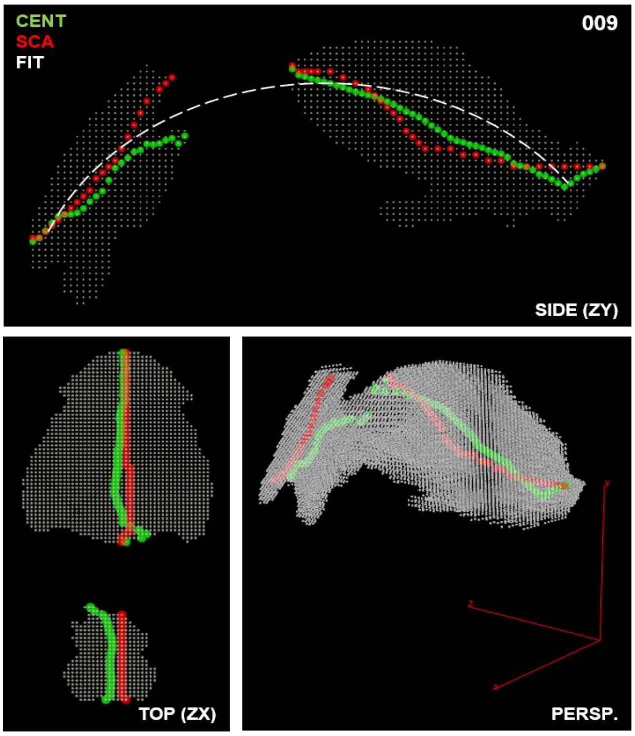

Figure 1: Laryngoscope blade build paths calculated by our procedural method shown in the airspace of the model

Two variants of space colonization algorithms (SCA), introduced by Runions et al. [5], generated the build paths for the isolated airway of each patient (Figure 2). Build

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paths were then fitted to a quadratic equation resembling the curvature of a standard laryngoscope blade. The curvature, width, and height of the parabola were recorded and compared to the dimensions of commercially available laryngoscopes.

III. Results and discussion

Our procedural method generated 3D reconstructions comparable to standard segmentation software such as Mimics and 3D Slicer. Future work will involve a quantitative analysis between our method and industry standards.

Patient specific blade paths, calculated by our procedural method and fitted to a quadratic equation, resulted into a smooth path of least resistance between the patient's mouth and epiglottis. The curvature, height and width of each blade was correlated to the age, weight, and height of the corresponding patient (Table 1). The strongest correlations found were between the patient's height and curvature (R^2=0.48), the patient's height and the width of the blade (R^2=0.41), and the patient's height and the height of the blade (R^2=0.40). While not significant on their own, these correlations were much greater than the relation between the patient's weight and curvature, width, or height of the blade (R^2=0.29, 0.23, 0.25). This is relevant because weight is the current metric for laryngoscope selection for the Verathon® laryngoscopes [3].

Table 1. Correlations

	N	*Curvature*	*Height*	*Width*
Age (mo.)	14	0.06	0.19	0.10
Weight (Kgs.)	13	0.29	0.23	0.25
Height (cm.)	11	0.48	0.40	0.41

Results show that conforming a blade design to the patient's anatomy generates a profile with dimensions that differ from the standard blade selected by patient weight. For example, the airway of a 17-month-old patient in our database, weighing 15.7Kgs, measured 30mm in length. Following Verathon® guidelines, because the patient weighs >10Kgs, the LoPro S2.5 would be selected for intubation. Keep in mind that the LoPro S2.5's blade measures >50mm in length. A 12-month-old patient from our database would have fallen short. Weighing 9Kgs, a 44mm long LoPro S2 would be used on this patient. However, our method measured his airway at 62mm in length. More direct comparisons between our database and Verathon® selection scale were consolidated in Figure 2. All the comparisons, airway length was defined as one dimensional (1D) length, drawn along the sagittal plane, from the oral cavity to the epiglottis. This length is equivalent to the width of the patient-specific blade calculated by our method.

It is important to note that our procedural method relies on the presence of air in the oral cavity during imaging. Unfortunately, not all cases had air in the oral cavity and therefore could not be a part of the data used in the study. Future work will address this issue by using rigid anatomical structures and features of the patient such as bones or the nasopharynx.

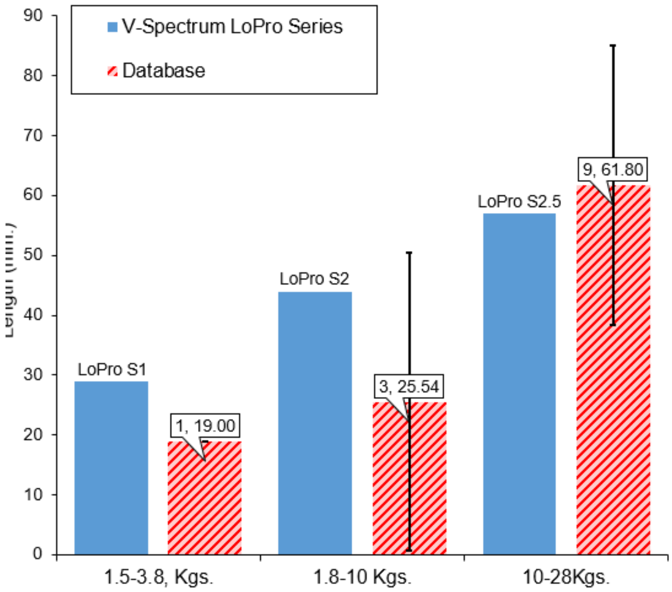

Figure 2: Comparison with standard laryngoscope sizes

IV. Conclusions

We have developed a semi-automated procedural method for design and fabrication of patient-specific pediatric laryngoscopes to highlight the size disparities in pediatric intubation. Using only weight as selection criteria does not account for anatomical variations that may require other blade geometries. These results and correlations are preliminary. An expansion of our patient database is needed to reach statistical significance.

Additional surgical procedures that we will be looking to in the future include vascular and endoscopic procedures which are all approached with traditional instruments of limited size and geometry configurations.

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Author's statement

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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