Clinical and surgical implications of intraoperative optical coherence tomography imaging for benign pediatric vocal fold lesions

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ABSTRACT

Introduction: Benign vocal disorders in children include an extensive list of abnormalities creating a variety of debilitating levels of dysphonia. Precise delineation of the benign lesion type and margins may have significant public health implications in children. An innovative technology such as optical coherence tomography (OCT) is being explored to delineate pediatric benign laryngeal lesions. An accurate assessment of the subepithelial morphology may help towards tailoring more personalized therapeutic treatments. This study was established to highlight key morphological and optical features of benign pediatric laryngeal lesions using intraoperative OCT and to suggest clinical implications that arise from such optical imaging.

Methods and materials: This in vivo study was performed at Massachusetts Eye and Ear Infirmary. Intraoperative imaging was performed on twenty-five pediatric patients ranging from 1 year to 16 years of age presenting hoarseness. Three-dimensional OCT images of benign laryngeal lesions or a subsite of the lesion were acquired.

Results: High-resolution OCT images of 25 patients with benign laryngeal lesions such as nodules, cysts, Reinke’s edema, vocalis sulcus, and papilloma revealed distinct and specific morphological differences with normal tissue. Nodules show a symmetrical superficial remodeling of the vocal fold epithelial layer and the basement membrane. Cysts have oval-like shape and are either superficial or deeply located in the lamina propria. Sulcus vocalis OCT imaging allows characterizing if the lesion is shallow or deep according to Ford’s classification system. Reinke’s edema of the mucosa can be observed and quantified, which may lead to suspicion on the underlying social and medical conditions. Finally, the ability to assess margins and depth of invasion of papilloma lesions is demonstrated, raising the possibility to use OCT with angiolytic lasers for patient-tailored treatments.

Conclusions: OCT imaging of benign pediatric vocal lesions is promising as it could improve preoperative decision-making and possibly peroperative imaging-guidance for patient-tailored treatments. An assessment of the optical contrast between healthy and abnormal tissue may help towards a more qualitative and quantitative approach to current standard care, especially when diagnosis remains unclear.

1. Introduction

Childhood is a period of anatomical and physiological changes susceptible to affect the larynx and its respiratory, phonatory functions. Arising as a consequence a vast array of laryngeal disorders is affecting this population, which have significant public health implications [1]. Over 5 million children are affected in the United States. School-aged children from 8 to 14 years [2] are the most affected age group with a reported prevalence of 3.9–23.4 percent [3–5]. During this critical developmental period, where communication skills and psychosocial abilities are pillars of a child identity, voice disorders may adversely impact an individual life by generating poor self-esteem and self-image [6]. Furthermore, children with unresolved voice disorders often need additional ongoing treatments into adulthood adding a substantial burden on the medical system [1] with several billion dollars in productivity loss [7,8].

Unsurprisingly, functional assessment of pathological voices in children remains challenging. Often dysphonia can persist or reoccur over a five-year period after the initial assessment, suggesting the importance of an early and accurate intervention [9]. The essential rationale is to identify and distinguish among benign vocal fold lesions, and potential malignant tumors. However, the etiology can be challenging to establish, as the underlying laryngeal symptoms are often nonspecific, subtle or infrequent. Moreover, dysphonia may originate...
from multiple cofactors such as behavioral, environmental or inherited [10]. As such, obtaining a thorough patient history with laryngoscopy is fundamental for dysphonic children.

Although the evaluation of laryngeal lesions can be achieved with a rigid or transnasal fiberscope, videolaryngostroboscopy remains the primary clinical tool to evaluate possible abnormal vibratory motion of the vocal folds [11]. Functional and biomechanical features such as amplitude, asymmetry, abnormal closure patterns and vibratory behavior, can be assessed in this fashion [12]. These features may refine diagnoses and provide better postoperative planning and voice management [13]. However, stroboscopy or high-speed video [6] examination is challenging to perform on children and is largely subjective to interpretation as vibratory patterns have yet to be correlated with pathological conditions [14]. Moreover, a certain subset of children are either too young or non-compliant to allow for successful office endoscopy. For these children, suspension laryngoscopy remains the gold standard diagnostic tool, where dysphonia is pronounced and diagnosis must be procured.

As many laryngeal pathologies have subepithelial roots, some lesions may remain invisible or hard to distinguish with the above imaging techniques. An additional method of contrast may improve clinical management of patients with voice disorders. As such, optical coherence tomography (OCT) has been used to evaluate non-invasively the adult and pediatric laryngeal anatomy [12-18]. Its potential to image the pediatric laryngeal mucosa, cricoid cartilage and tracheal rings has been shown [15,16]. However, most studies so far have been focused on adult laryngeal diseases, and a very few have addressed pediatric benign vocal fold lesions such as vocal nodules, cysts, polyps, Reinke’s edema and sulcus. The optical contrast between healthy and abnormal tissue may help towards a more qualitative and quantitative approach to current standard care, especially when diagnosis remains unclear. Clinicians should be aware of new and modern imaging modalities to aid therapeutic decision-making. The purpose of this study is to characterize the key morphological characteristics of benign pediatric vocal fold lesions using OCT and to correlate with clinical insights that correspond to intraoperative optical images of these lesions.

2. Materials and methods

2.1. Patient population

OCT imaging was performed on 25 dysphonic pediatric patients (n = 12 male, n = 13 female) ranging from 1 year to 16 years of age undergoing direct laryngoscopy under general anesthesia. Parents were informed, and written consents were obtained before intraoperative examination. As a comparative baseline, OCT images acquired on healthy laryngeal tracts from a previous study [17] were used. This study was performed at Massachusetts Eye and Ear Infirmary under the approval of the Institutional Review Board.

2.2. Instrumentation

The intraoperative OCT system used in this study was previously described [17,18]. The swept-source system is based on vertical-cavity surface-emitting laser source [19,20] centered at 1300 nm (SL1310V1, Thorlabs) with a tuning range of 110 nm (at full width at half maximum). Imaging of laryngeal lesions is achieved with a 3.6 mm handheld rigid scope, which is enclosed by a translucent disposable sterile sheath (0.2 mm thickness, Slide-ON Endosheath, Medtronic). The probe was designed for accurate positioning and rapid volumetric OCT imaging of the airway. Orientation laser marks along the stainless tube orient the clinician and fast galvanometers (621SH, Cambridge Technology) allow three-dimensional data to be acquired under 18 s (2, 2, and 5 mm, 1040 × 1040 × 1040 voxels). The system axial and lateral resolution is respectively 12 and 25 μm in tissue.

### Table 1

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<th>Lesion</th>
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<td>Male</td>
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<td>Nodules</td>
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<td>Cyst</td>
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<td>Reinke Edema</td>
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2.3. Intraoperative imaging

Patients underwent a perceptual and a visual examination, before each intraoperative intervention. Conventional and OCT imaging were performed under suspension laryngoscopy. The glottis, including the anterior commissure, was exposed with a Lindholm laryngoscope for direct laryngoscopy (0°, 4 mm, Storz). Under endoscopic guidance, the handheld OCT probe tip was precisely positioned on each suspicious lesion or a sublarynx of the lesion. Positioning the probe and imaging both vocal folds extents the OCT imaging procedure by 45 s. When possible, lesion images were acquired with the surrounding tissue for delineation of margins. OCT cross-sections are displayed in logarithm scale (heat colormap, –84 dB) with the signal intensity proportional to the optical scattering coefficient. Endoscopic images were recorded and correlated with OCT for further analysis. All images are in the same orientation as acquired in the surgical setting. We used data previously obtained characterizing normal pediatric vocal fold with OCT [17] to compare with abnormal pathologies. This database represents a collection of longitudinal scans, which cover the true vocal fold and the subglottic region (up to 6 mm). Table 1 illustrates the gender distribution of patients imaged with laryngeal lesions in this study.

3. Results

All patients (n = 25) have been successfully imaged during suspension laryngoscopy with no follow-up complications. Clinical and optical observations are provided for different lesion imaged such as nodules (n = 9), cysts (n = 4), Reinke’s edema (n = 2), vocalis sulcus (n = 2), and laryngeal papilloma (n = 8). As a baseline, a description of the normal laryngeal tract is first presented.

3.1. Intraoperative imaging of the glottis

A typical intraoperative view of a healthy 2-month-old aerodigestive tract (Fig. 1A) reveals both vocal folds pearly white and ab ducted, forming a V-shape structure. The free edges of the vocal folds are symmetrical with no appearance of lesions. The coronal schematic larynx section (Fig. 1B) highlights the most relevant structures of the human glottis and the subglottic region, which illustrates the stratified squamous nonkeratinized epithelium (SSE), pseudostratified columnar epithelium (PSE), lamina propria (LP), vocalis muscle (TA), mucouser glands (MG), thyroid cartilage (T), cricoid cartilage (C), and cri cothyroid muscle (CT).

The ability to delineate the mucosa layers based on the optical tissue properties is clearly demonstrated on the corresponding aerodigestive tract OCT cross-section (Fig. 1C). The vocal fold mucosa is characterized by a thin stratified squamous epithelial layer, predominantly cellular, and with its underlying lamina propria, mostly gelatinous. The basement membrane anchors the epithelium to the superficial lamina propria. This junction is of major interest as it is sensitive to trauma [21] and cancer cells [22]. Inferiorly to the vocal fold edge, the epithelium layer thickens. This thickening is attributed to the transition from SSE to PSE cells. This was confirmed with histopathology sections from previous ex vivo studies [18,23]. The TVF lamina propria is
relatively homogenous and hyperlucent (highly scattering). However, near the strike zone (edge of TVF), a distinct intensity region is observed, which may suggest a different density of elastin and collagen fibers [24]. In contrast, the LP of the subglottic region is heterogeneous with a group of small-branched tubuloalveolar glands. These seromucinous glands weakly scatter light and appear approximately 200 μm deeper from the basement membrane. Laryngeal microstructures remain visible within 1.8 mm deep. Beyond this depth, light penetration is highly attenuated by the tissue optical properties (scattering and absorption). However, the TA muscle delineation is suggested by the optical contrast of the deep LP layer.

3.1.1. Bilateral nodules

Vocal fold nodules are bilateral swelling often located at the junction of the anterior and the middle thirds of the vocal folds as shown in Fig. 2A. This location is the point of maximal shearing and collision forces between the anatomical vocal structures [25,26]. This extra anterior mass increases the vocal fold stiffness, therefore, affecting vibration and closure [27]. Nodules arise mainly from chronic voice abuse (hyperfunction) or reflux disease. It is believed that nodules may first start as submucous edema and further manifest signs of hyperkeratotic epithelium with fibrosis [28,29]. Therefore, these lesions affect the epithelial layer and remain superficial as illustrated in a coronal schematic section of the larynx (Fig. 2B).

In this study, all patients with nodules (n = 9) showed signs of moderate to severe hoarseness. Direct laryngeal endoscopy revealed a variation of nodules in size, color and slightly in location and symmetry. While there are some small series reports of grading scales to quantify nodules [30], there is no universally accepted grading scale. However, lesion size is most commonly correlated with the extent to which a child show signs of hoarseness, breathiness, straining, and aphony [31].

The corresponding nodule OCT cross-section (Fig. 2C) shows the lesion slightly inferior to the free edge of the vocal fold and marked by a significant epithelial thickening. This hyperkeratotic region was observed in all patients with nodules, which averaged to 0.5 ± 0.3 mm in thickness at its maximum height. At the lesion site, the optical contrast with the underlying superficial lamina propria is attenuated compared to the surrounding tissue. This is especially noticeable at the center peak of the nodule. This hypolucent region (weakly scattering) may well be an excessive fibronectin deposition with collagen type IV [32,33]. Fibronectin is a prominent glycoprotein found in wound sites, which enables other macromolecules to bind together for scar formation. It is believed to be a permanent event [34] and may explain why some nodules do not respond to therapy. A recent study [35] showed that after voice therapy approximately 31% (22 of 70) of nodules were reduced in size and only 11% (8 of 70) were completely resolved. Furthermore, histological studies have suggested that the basement membrane in nodules may be disorganized or damage [32,33], which may further explain the loss of optical contrast observed in this region. OCT nodule features are found to be similar on both vocal folds, suggesting the same tissue traumatic response.

Primary treatment of pediatric symptomatic vocal nodules consists of a several-month course of voice therapy [35].
are taught proper breathing techniques and muscle relaxation to eradicate any phonotraumatic behaviors. Decreasing hyperfunctional vocal behavior may lead to a significant improvement of voice quality and may lead to some reduction of nodule size. However, the bilateral swelling may still be apparent under endoscopy. This suggests that the chronic nature of reinjury in vocal fold nodules during phonation triggers a remodeling of the mucosa, which explains why there may be acoustic benefits to therapy while there still remain pathological changes in the vocal fold microstructure.

3.1.2. Cysts

Vocal fold cysts are usually unilateral. However, a reactive vocal fold lesion such as callus is often observed on the contralateral cord, which can often be misinterpreted with bilateral nodules without a cyst under. Similarly, cysts have an intracordal mass, which increases stiffness and disrupt the vocal fold vibratory pattern, resulting in significant dysphonia. The size and location of cysts can vary along the vocal fold. Although there are two major cyst subtypes: mucous-retention and epidermoid cysts, it is difficult with endoscopy alone to identify the subtype. A mucous-retention cyst arises from obstructed mucous gland ducts, while epidermoid cysts can be congenital or emerge from vocal trauma, which results in accumulation of keratinaceous debris.

Fig. 3A and Fig. 3D show intraoperative views of an epidermoid cyst on a 5-year-old girl and a mucous-retention cyst on a 3-year-old girl, respectively. The epidermoid cyst is located on the left midmembranous part of the true vocal fold (Fig. 3A) and appears as local swelling of the mucosa. A significant contralateral reaction is visible on the right vocal fold. However, the lesions remain asymmetric as the left vocal fold lesion has more prominence and volume. The corresponding OCT cross-section (Fig. 3B) shows an oval-shape cyst well outlined inside the lamina propria. The epithelial lining (EPL) cyst is defined by this dark band (low scattering region) of approximately 60 μm thick, which encapsulate a mixture of protein, mucin, and cellular debris. Mucus-retention cysts are usually more translucent lesions as shown on the right vocal fold of a 3-year-old girl with prolonged dysphonia (Fig. 3D). Under office evaluation, the lesions seemed anterior and relatively symmetric. However, it remained unclear if those lesions were nodules or possible cysts. Under suspension laryngoscopy, a slight asymmetry was observed with more depth on the right vocal fold lesion. The corresponding OCT cross-section (Fig. 3E) shows the subepithelial mucous-retention multiloculated cyst appearing within the superficial part of the lamina propria with no visible epithelial encapsulation. The lesion is heterogeneous with hypoluent regions, suggesting fluid-filled sacs in the lamina propria. Mucus-retention cysts seen in this study appeared within the superficial LP as opposed to epidermoid cysts for which have been seen more deeply in the LP as illustrated in Fig. 3F and C.

Traditionally vocal cysts are not thought to respond to voice therapy as well as phonotraumatically induced vocal nodules. Therefore, prolonged courses of voice therapy might well be avoided if vocal lesions were known to be definitively cysts, not nodules. A shorter course of voice therapy might still be prescribed to reduce phonotraumatic vocal behavior and potentially lessen the development of postoperative scarring after cyst removal. Cysts surgical excision may worsen and not improve the voice quality, and this is one of the critical features where OCT may be clinically helpful. For instance, in Fig. 3B, given the size, depth, and volume of the cyst, removing this lesion might produce a
crater deformity and a potential sulcus formation given the absence of LP. Therefore, cysts depth and margins may help in evaluating risks, informing parents and ultimately improving decision-making.

3.1.3. Sulcus vocalis

Fig. 4A shows an intraoperative view of a sulcus on the right vocal fold of an 11-year-old girl. The lesion is near the vocal fold edge oriented parallel to its length. Sulcus vocalis is characterized by a mucosa depression along the medial surface of the vocal fold that results from the loss of the lamina propria. The infolding can stretch to the entire length of the vocal fold creating a glottal gap and subglottal pressure deficiency. The absence of an extracellular matrix reduces the viscoelasticity and vibratory capability of the vocal fold [37]. Therefore, patients may suffer from profound dysphonia and voice handicap [38].

The clinical description consists of a harsh and weak voice, which requires substantial effort during phonation [39].

A 3-tiered sulcus classification system was identified by Ford and colleagues [40] in order to improve the management of this lesion. Fig. 4C shows an illustration of the Ford classification system. Type I sulcus vocalis is asymptomatic with a subtle depression along the superficial lamina propria. Type II sulcus presents moderate dysphonia and involves a deeper depression that extends to the vocal ligament. Type III sulcus vocalis is the most severe type. The invagination extends beyond the vocal ligament into the thyroarytenoid muscle.

Although the mucosa depression can be assessed by palpation during direct laryngoscopy with a blunt right-angle probe (Fig. 4B), it is challenging to estimate how much of the full length of the lamina propria is absent. The corresponding OCT cross-section of the vocalis sulcus (Fig. 4C) allows visualizing the invagination of the epithelial layer, which runs parallel to the free edge. While the epithelium is slightly thicker along the depression, the sulcus depth is amplified at the mid-length of the vocal fold. The mucosa infolding is 1 mm inferior from the free edge and 800 μm deep within the LP. The groove does not seem to reach the TA muscle. However, the depression may be deep enough to be classified as a type II sulcus. The area of the vocal fold is split in two, and therefore it cannot be normal and is prone to stiffness. The contrast in superior part, near the strike zone, is different from the inferior region. The inferior part appears to show a layered structure, which is similar to what is seen in healthy patients, therefore suggesting that the two regions may have different biomechanical properties.

The evaluation and management of sulcus vocalis remain challenging due to the limited tools and clinician awareness. There still no consensus regarding the origin of this lesion and treatments are controversial. Voice therapy can be useful for proper glottic closure. However, depending on the severity, different approaches are available, among which, a medialization thyroplasty, collagen or corticosteroid injections, alloplastic, fat and fascia fillers can be used. In this study, all sulcus cases encountered showed moderate dysphonia and voice therapy was suggested as a first treatment except for the case presented (Fig. 4A) in which dysphonia was severe, and a Gray's minithyrotomy [41] with fat augmentation was performed.

3.1.4. Bilateral Reinke’s edema

Fig. 5A shows an intraoperative image of an 11-year-old girl with Reinke’s edema. The medial surface of both vocal folds is slightly bulging and swelling due to the fluid. Reinke’s edema is characterized by little pockets of fluid-filled sacs located within the superficial part of the lamina propria. Additionally, signs of hypervascularity are visible on the surface of the true and false vocal folds. Vocal abuse,
gastroesophageal reflux, and smoking are frequently associated risk factors for this lesion [42,43]. Furthermore, previous aerodynamic studies have observed an increased subglottic pressure, which produces a lower fundamental frequency on patients [44]. The OCT cross-section in Fig. 5B shows a representative edema region with a fusiform shape within the lamina propria.

The OCT cross-section acquired during the evaluation shows an apparent void (Fig. 5C). This darker region extends medially towards the edge of the vocal fold. This is likely to be extra viscous fluid trapped inside the superficial part of the lamina propria. A non-turbid medium would generate a higher scattering signal, similarly to an epidermoid cyst, previously illustrated in Fig. 3C. Although endoscopy reveals an irregular vocal fold edge, the OCT images show no signs of hyperplasia or abnormal thickening of the epithelial layer. Similar results have been reported in a previous histologic study [42], showing no signs of hyperplasia, dysplasia or keratosis in 41% (51 of 125). The signal within the lamina propria manifests a more heterogeneous signal, which may be explained by loose, edematous and disorganized elastin and collagen fibers.

Voice therapy was suggested in all edema cases to reduce the localized edema and further improve voice quality. While all cases seen showed mild edema in moderate and severe cases phonosurgery may be more appropriate depending on the degree of hoarseness and airway impairment. OCT may be useful to screen and quantify early stage of Reinke’s edema for underlying social and medical conditions or phonation impairment. OCT does not allow seeing the depth of invasion.

Furthermore, the lamina propria seems to show different scattering properties at different regions along the aerodigestive tract. Some regions are compressed, which would suggest a different elastin and collagen density, reducing the overall reflected backscattering light. The disruption of the basement membrane or a loss of optical contrast between the epithelial layer and the lamina propria could be a sign of early microinvasive squamous cell carcinoma [23,48]. However, all cases seen in this study showed a basement membrane demarcation along the aerodigestive tract, suggesting no malignant conversion.

Although some new antiviral agents have been developed, RRP therapeutic treatments remain challenging, and there remains no cure to address this pathology. Considering that these lesions have a propensity to recur, the goal of therapy is to relieve airway obstruction while preserving voice and the underlying healthy structures. Patients evaluated show different degrees of hoarseness related to the stiffness of respiratory papillomatosis. The papillomas have a pinkish color with red spots, and are located on both vocal folds reaching the right surface going into the ventricle. These lesions can develop in the entire larynx. They have a predilection to spread on the vocal folds at the laryngeal junction of squamous and respiratory epithelium [47]. They are persistent and recurrent exophytic fibrovascular lesions. As shown the mucosa is largely altered and a hypervascularization of the surrounding tissues is visible. Its impact on the layered microstructure is portrayed in Fig. 6B.

The corresponding OCT cross-section (Fig. 6C) reveals a significant change in the microanatomy of the true vocal fold in comparison with normal tissue (Fig. 1C). First, there is a substantial increase in epithelial thickness along the glottis and the infraglottic region. This observation can be related to epithelial hyperplasia (EH) commonly seen in papilloma lesions. It is important to note that papilloma’s infection in the infraglottic region may not be revealed by endoscopy alone. As it is essential to visualize all papilloma lesions alternative technologies such as narrow band imaging have also been explored [49,50]. However, this technique does not allow seeing the depth of invasion.

3.1.5. Papilloma

Laryngeal papillomatosis is the most common form of benign tumors of the larynx in children [45]. It is a viral infection caused by human papillomavirus of serotype 6 and 11 [46]. Fig. 6A shows the intraoperative view of a 4-year-old boy glottis with recurrent respiratory papillomatosis. The papillomas have a pinkish color with red spots, and are located on both vocal folds reaching the right surface going into the ventricle. These lesions can develop in the entire larynx. They have a predilection to spread on the vocal folds at the laryngeal junction of squamous and respiratory epithelium [47]. They are persistent and recurrent exophytic fibrovascular lesions. As shown the mucosa is largely altered and a hypervascularization of the surrounding tissues is visible. Its impact on the layered microstructure is portrayed in Fig. 6B.

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the vibratory vocal fold due either to lesions or, to the vocal fold postoperative scarring from past treatments or, from glottal aperture defects. Treatments were tailored to the specific needs of each patient based on the aggressiveness and the severity of the infection. Surgical debulking of papillomas was performed on all patients (n = 9) with an angiolytic laser and a microdebrider. Depending on the severity of the infection, the surgical procedure was followed, in some cases (n = 4), with an injection of bevacizumab.

Postoperative RRP treatment efficacy is difficult to assess. RRP lesions are often heterogeneous and spatially non-uniform. A classification system was previously proposed to evaluate the effect of laser treatments [51]. Without a real-time quantitative assessment of subepithelial structures, it may be very challenging to find the right amount of the energy to be delivered to the lesion while avoiding collateral damage to surrounding tissue. We believe that OCT could be used as a depth-guidance intraoperative tool to monitor and control laser treatments.

4. Discussion

The vast majority of dysphonic children do not require general anesthesia and sedation for operative laryngoscopy and suspension laryngoscopy to make a clinical diagnosis. For those that do, where a child will not tolerate office laryngology or where diagnosis remains unclear, OCT imaging clearly helps to differentiate between benign vocal fold lesions, which heretofore have been difficult to distinguish between. The clinical utility of securing such a diagnosis is vastly important. If indeed voice therapy is the primary treatment modality for children with vocal nodules [16] whereas its efficacy is far lower in children with vocal fold cysts, then cinching a diagnosis of vocal nodules becomes important to save children unnecessary time off school and parents and caregivers unnecessary time off work. For the child with a vocal cyst, where phonosurgery is being considered, the actual size, three-dimensional volume, and depth of the vocal fold cyst becomes very important to know in order to inform the child-parent and caregiver about postoperative vocal expectations. Therefore, surgery may or may not be indicated in some cases. For vocal sulci, it can be difficult to characterize if the lesion is shallow or deep according to Ford’s classification system and to grade them by physical inspection or even instrumentation. Accurate classification of the depth of vocal sulci can allow for more precise surgical planning ranging from fat injections [18,19] to Gray’s minithyrotomy approach [20]. An observation noteworthy is the precise margins delineation of laryngeal edema and laryngeal papilloma, which may have significant clinical relevance. It would be a critical step forward if ultimately tailored treatments were provided while preserving the underlying normal anatomy. Although benign lesions may be located at a different part along the length of the vocal fold, our results suggest that lesions seem to be a little more inferior (approximately 1 mm) from the edge of the vocal fold (strike zone). This might be related to the initial mucosal wave formation or high aerodynamic pressure points. However, the exact reason for this anatomical finding remains unclear at this point.

We present in this study high-resolution images of various benign pediatric lesions acquired using an intraoperative OCT endoscopic probe. Optical coherence tomography allows close inspection of even the most subtle microstructural changes within the aerodigestive tract,
overcoming the insufficient contrast or sensitivity of current radiographic imaging techniques. Although the results of this initial work are compelling, there are several weaknesses to this study that limit the generalizability of the findings. First, this is a limited sample set, and further analysis might be refined with higher sample size. At this point, the probe remains a contact probe. This feature enhances the image quality but limits its translation to an office-based setting. A non-contact probe design would substantially increase its utility. In certain circumstances like papilloma lesions, it would be beneficial to be able to diagnose and treat with the same instrument to optimize care, and such research and development is currently underway in our laboratory. Furthermore, this OCT system and its probe itself are not yet commercially available for routine usage elsewhere. Nevertheless, the ability to define the OCT characteristics both of normal and pathologic anatomy is crucial to allow to delineate normal from abnormal tissue as well as to allow greater insight into individualized difficult clinical scenarios where the diagnoses, with current technology, remain murky.

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**Conflicts of interest**

The authors have no financial relationships or conflicts of interest to disclose.

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