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# Intraoperative long range optical coherence tomography as a novel method of imaging the pediatric upper airway before and after adenotonsillectomy

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A B S T R A C T

*Background/Objectives:* While upper airway obstruction is a common problem in the pediatric population, the first-line treatment, adenotonsillectomy, fails in up to 20% of patients. The decision to proceed to surgery is often made without quantitative anatomic guidance. We evaluated the use of a novel technique, long-range optical coherence tomography (LR-OCT), to image the upper airway of children under general anesthesia immediately before and after tonsillectomy and/or adenoidectomy. We investigated the feasibility of LR-OCT to identify both normal anatomy and sites of airway narrowing and to quantitatively compare airway lumen size in the oropharyngeal and nasopharyngeal regions pre- and post-operatively.

*Methods:* 46 children were imaged intraoperatively with a custom-designed LR-OCT system, both before and after adenotonsillectomy. These axial LR-OCT images were both rendered into 3D airway models for qualitative analysis and manually segmented for quantitative comparison of cross-sectional area.

*Results:* LR-OCT images demonstrated normal anatomic structures (base of tongue, epiglottis) as well as regions of airway narrowing. Volumetric rendering of pre- and post-operative images clearly showed regions of airway collapse and post-surgical improvement in airway patency. Quantitative analysis of cross-sectional images showed an average change of 70.52 mm$^2$ (standard deviation 47.87 mm$^2$) in the oropharynx after tonsillectomy and 105.58 mm$^2$ (standard deviation 60.62 mm$^2$) in the nasopharynx after adenoidectomy.

*Conclusions:* LR-OCT is an emerging technology that rapidly generates 3D images of the pediatric upper airway in a feasible manner. This is the first step toward development of an office-based system to image awake pediatric subjects and thus better identify loci of airway obstruction prior to surgery.



## 1. Introduction

Sleep disordered breathing is well recognized in children, with the spectrum ranging in severity from primary snoring to obstructive sleep apnea (OSA) [1,2]. OSA affects up to 3% of children and is characterized by a combination of partial and complete airway obstruction that disrupts normal ventilation during sleep [1,2]. Diagnosis and treatment of OSA are of importance because of significant co-morbidities in children, including neurocognitive disturbances and cardiovascular dysfunction [3–12].

Adenotonsillar hypertrophy is a leading contributor to the development of pediatric OSA, and while adenotonsillectomy remains the first-line intervention, it fails in up to 20% of patients [1,13]. The decision to proceed with surgery is based on clinical judgment, most often without any quantitative anatomic guidance. Computed tomography (CT) and cine magnetic resonance imaging (MRI) are not routinely ordered due to cost, radiation exposure, and/or need for sedation [14–17]. Knowing the internal structure of the upper airway is critical in patients

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where clinical judgment has limited reliability or in children with comorbidities that make identifying the location of obstruction(s) a challenge (e.g., craniofacial deformities). In these more subtle and challenging cases, it would be especially beneficial for clinicians to have an in-office system that could either verify adenotonsillar hypertrophy as the source of symptoms, or identify other regions of the upper airway contributing to the obstruction, with the intention of better predicting outcomes and reducing treatment failure.

Recently, long-range optical coherence tomography (LR-OCT) has been developed to image the airway via transnasal placement of an optical fiber assembly [18–20]. LR-OCT is a variation of traditional optical coherence tomography which uses time-of-flight measurements for coherent photons to determine the distance between a fiber tip and a target surface [21]. These measurements have been previously compared to CT images and known-diameter models to demonstrate accuracy [18–20,22,23]. LR-OCT can be used to identify air-tissue interfaces across long distances (~3–10 cm) [24,25]. Incorporating a rotary fiber optic system with linear pullback, information about the structure of hollow viscera in the human body can be obtained. There is no ionizing radiation exposure. With LR-OCT imaging, the entire airway can be scanned from hypopharynx to nare in approximately 20–40 s, making this an efficient method of studying upper airway anatomy [26].

This study involved the use of LR-OCT to image the pediatric upper airway (from pyriform sinus to choana) in children undergoing tonsillectomy and/or adenoidectomy. The LR-OCT study was performed both immediately before and after the surgery under general anesthesia. We investigated the feasibility of LR-OCT to identify both normal anatomy and sites of airway narrowing. The axial LR-OCT images were used to quantitatively compare airway lumen size in the oropharyngeal and nasopharyngeal regions pre- and post-operatively. The spiral LR-OCT scans were used to construct pre- and post- operative 3D models of the pediatric upper airway, which were evaluated qualitatively. This is the first large-scale evaluation of LR-OCT use in the pediatric upper airway and is a critical first step toward using this technology to precisely identify airway obstruction in awake children.

## 2. Methods

### 2.1. Study subjects

Children undergoing adenotonsillectomy ($n = 29$), adenoidectomy ($n = 16$), or tonsillectomy alone ($n = 1$) were imaged under the aegis of the Human Subjects Institutional Review Boards at Children's Hospital of Orange County and the University of California, Irvine. Informed consent was obtained from parents prior to surgery. All studies were performed at Children's Hospital of Orange County. Inclusion criteria included any child undergoing tonsillectomy and/or adenoidectomy. Exclusion criteria included patients with craniofacial disorders or syndromic abnormalities such as Down syndrome or the facio-auriculo-vertebral spectrum.

### 2.2. Frequency domain long-range optical coherence tomography

The LR-OCT system used in this study (Fig. 1A) has been described previously [26]. It is a frequency domain swept source OCT system with axial resolution of 10 μm in tissue. The lateral resolution at the focal point of the probe is 112 μm [26].

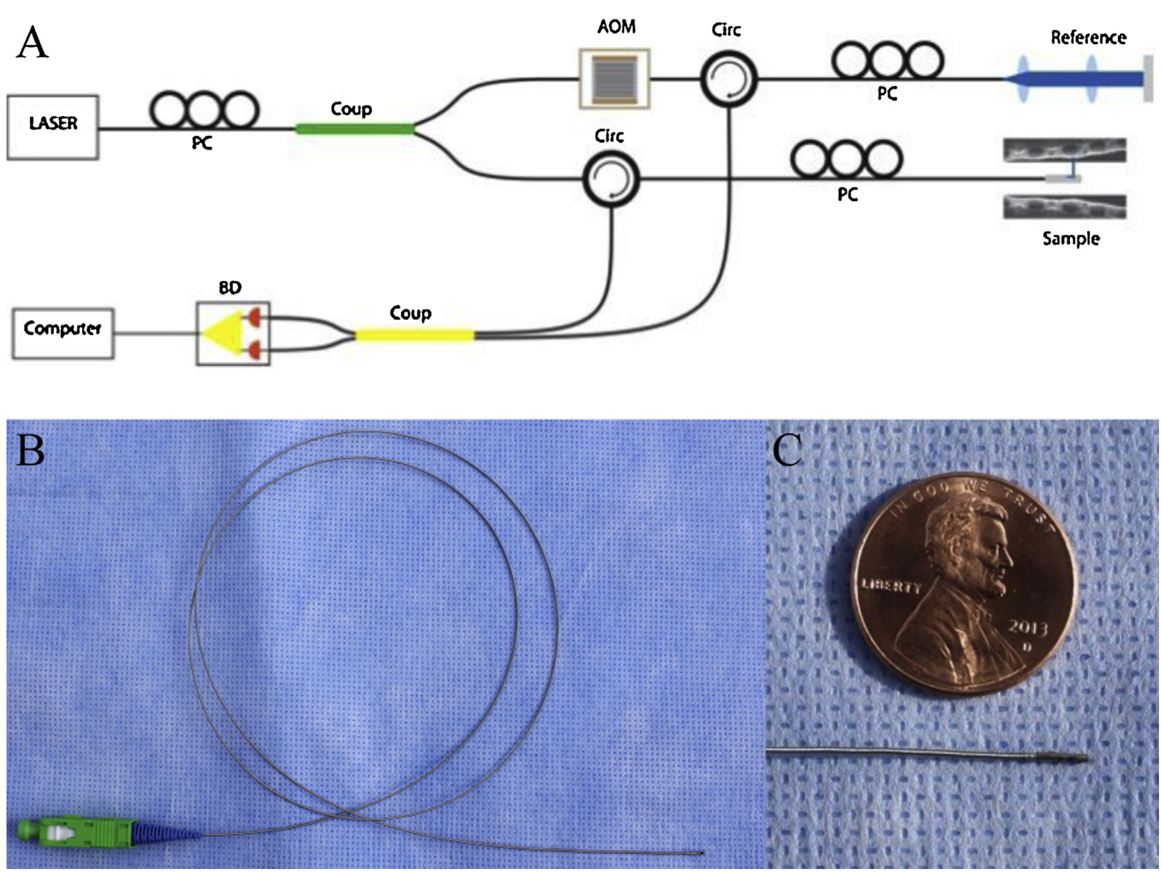


**Fig. 1.** (A) Schematic of LR-OCT system. PC = Polarization controller, Coup = Coupler, AOM = Acousto-optic modulator, Circ = Circulator, BD = Balanced detector. (B) 0.7-mm optical imaging probe. (C) Enlarged view of the probe tip.