Near-Infrared Optical Imaging for Diagnosis of Maxillary Sinusitis

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Abstract
Computed tomography (CT) is the current gold standard imaging for chronic rhinosinusitis (CRS) but is limited by cost, risk of radiation, and difficulty of being performed in the typical outpatient primary care setting. We describe the novel use of a low-cost, handheld technology to deliver an intraoral near-infrared (NIR) wavelength light to optically image the maxillary sinuses. Digital images were collected for subjects presenting with sinus disease using an intraoral NIR light source for transillumination of the maxillary sinuses, captured by a modified digital single-lens reflex camera. Light intensity contrasts were enhanced using computer analysis and subsequently compared to CT findings. NIR illumination produced unique patterns reflecting different disease states: normal sinus anatomy, mild sinus disease and/or mucosal thickening, and complete opacification of the sinus. Current results suggest that NIR imaging may facilitate the diagnosis of sinusitis in the outpatient setting with minimal cost and no radiation exposure.

Keywords
acute sinusitis, chronic sinusitis, imaging, transillumination, maxillary sinusitis, maxillary sinus

Materials and Methods

Patients
The University of California Irvine Institutional Review Board approved this study. Participants were recruited from a tertiary care rhinology practice, and informed consent was obtained. The inclusion criteria were age ≥15 years and had normal computed tomography (CT) imaging.4 By combining clinical diagnosis with imaging, diagnostic accuracy could be improved.

In the case of chronic rhinosinusitis (CRS), guidelines recommend obtaining corroborating evidence for diagnosis by either nasal endoscopy or imaging.5 Neither of these modalities is available in the typical primary care physician office. Furthermore, patients with CRS can have normal nasal endoscopy results, which can make the in-office diagnosis of CRS based on clinical findings alone equally difficult for many otolaryngologists.

Although CT imaging is available in select otolaryngologists’ offices, this modality exposes patients to ionizing radiation and increases cost. X-rays are inexpensive but subject patients to radiation while providing less diagnostic information. Magnetic resonance imaging involves no radiation exposure but is expensive and time-consuming. Thus, a simple, low-cost, office-based technique may be useful in the diagnosis of CRS.

Near-infrared (NIR) spectroscopy has not been previously investigated as a sinus imaging modality. Here we report a preliminary investigation into the use of a simple NIR light source to transilluminate the maxillary sinuses to assess the presence and extent of sinonasal disease.

In the United States, approximately 1 in 8 people develop sinusitis each year, and >$11 billion per year is spent on evaluation and treatment.1 Guidelines are published by the American Academy of Otolaryngology—Head and Neck Surgery Foundation; however, diagnosing sinusitis remains challenging because symptoms often overlap with other conditions.1-3

Acute rhinosinusitis is diagnosed by history, but studies comparing clinical diagnosis and radiographic results have shown that clinical diagnosis is often inaccurate. A recent prospective study demonstrated that 30% of patients diagnosed with acute rhinosinusitis by a primary care physician

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

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This article was presented at the 2015 AAO-HNSF Annual Meeting and OTO EXPO: September 27-30, 2015; Dallas, Texas.

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concurrent CT (<2-week interval) of the sinuses. Patients with previous sinus surgery and patients with intervening therapy before the scan were excluded.

Imaging Setup
The clinical imaging setup and a sample image are shown in Figure 1. NIR imaging was performed in a darkened room without windows to eliminate ambient light. A probe developed by Praxis Biosciences, Inc (Irvine, California) with NIR light-emitting diodes on a flexible circuit encased in an acrylonitrile butadiene styrene foam was covered in a disposable polyethylene bag for infection control. This was inserted intraorally and held against the hard palate. Images of the NIR light transmitting into the maxillary sinuses were obtained at 3 preset exposure times by a standard digital single-lens reflex camera with its infrared blocking filter removed (Canon EOS Rebel T3). The camera was focused on the face from a distance of 18 inches with a fast-aperture lens (f/1.8). Image acquisition was completed in 5 to 10 seconds.

Analysis
Images were stored securely, and only the red channels were analyzed. Fifteen isointensity contour lines were created to delineate an intensity gradient for each image. NIR images were compared with concurrent CT images.

Results
NIR images were obtained for 45 patients. No patient reported discomfort or requested termination of imaging. Technique evolved throughout the study to improve image quality. After the first image acquisitions, modifications in technique were implemented. For example, having the patient place a hand over the lips helped to eliminate a bright signal from the mouth.

Normal subjects displayed a glow of diffusely transmitted NIR light throughout the maxilla (Figure 2). Contour images reveal underlying pattern of high-intensity symmetric peaks below the lower eyelids. The corresponding CT images show clear maxillary sinus cavities.

Characteristic variations in NIR images associated with mucosal sinus thickening (Figure 3) or sinus opacification (Figure 4) on CT are shown. These images show notable loss of symmetry due to increased light absorption from the sinus contents, resulting in diminished peak intensities below the lower eyelids to varying degrees.

Discussion
These pilot results indicate that NIR imaging of the maxillary sinus may be useful for diagnosis of maxillary sinusitis. When compared with bulk CT findings, variations in NIR image patterns appear to differentiate normal presentation, mild sinus disease, and complete opacification.
There are several potential benefits of this technology. NIR imaging could be utilized in a point-of-care setting to provide objective data to reduce the inappropriate use of antibiotics in patients without sinusitis. Furthermore, NIR imaging can be performed rapidly without exposure to radiation, and it is inexpensive. The cost of imaging hardware is estimated to be <$500, which is below the pricing requirements for most primary care clinics. However, clinicians should still utilize any imaging modality as a tool for diagnosis only in conjunction with patient history and examination.

It is important to note that this was a preliminary study with a small sample size to assess the capability of the technology. Individual patient factors, such as soft tissue and bony characteristics, prevent comparison of images among patients or the establishment of universal light intensity thresholds. Further investigation would study parameters of validation, including sensitivity and specificity, as well as interrater reliability and construct validity. Ultimately, we will examine cost-effectiveness and role relative to other imaging modalities.

**Conclusion**

NIR transillumination of the maxillary sinus is a simple and inexpensive imaging modality that can be performed in the outpatient setting to potentially diagnose maxillary sinusitis. Further study is necessary to better characterize the exact role of NIR relative to other imaging options.

**Acknowledgments**

We thank Joon You, PhD, and Haotian Cui for their technical assistance with the imaging system. We also thank Mackenzie Reynolds and Montana Compton for their assistance in patient data collection and coordination.

**Author Contributions**

Carolyn A. Coughlan, data analysis, drafting the manuscript, revision of the manuscript, final approval, accountability for all aspects of the work; Albert E. Cerussi, conceptual design, data analysis and interpretation, revision of the manuscript, final approval, accountability for all aspects of the work; James Kim, data collection, revision of the manuscript, final approval, accountability for all aspects of the work.
all aspects of the work; **Sean Ison**, data collection, revision of the manuscript, final approval, accountability for all aspects of the work; **Naveen D. Bhandarkar**, conceptual design, data analysis and interpretation, revision of the manuscript, final approval, accountability for all aspects of the work.

**Disclosures**

**Competing interests:** None.

**Sponsorships:** This work was supported by the National Institutes of Health, National Institute on Deafness and Other Communication Disorders.

**Funding source:** National Institutes of Health (R44-DC012018-01SBIR).

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