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Initial findings of shortwave infrared otoscopy in a pediatric population

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ABSTRACT

Objective: To evaluate the feasibility of Shortwave infrared (SWIR) otoscopy in a pediatric population and establish differences with visible otoscopy.

Methods: Pediatric patients 3 years of age and older seen in the otolaryngology clinic with an audiogram and tympanogram obtained within a week of the visit were recruited for video otoscopy using visible light otoscopy and SWIR otoscopy. Videos were rated by two otolaryngologists based on ability to identify the promontory, ability to identify the ossicular chain and presence or absence of middle ear fluid.

Results: A total of 74 video recordings of ears were obtained in 20 patients. We obtained interpretable images in 63/74 (85.1%) ears. There was no statistical significance between ability to perform SWIR otoscopy versus white light video otoscopy as indicated by a *p*-value of 0.376.

There was high inter-rater agreement for identification of both the promontory and the ossicular chain with Kappa values of 0.81 and 0.92 respectively. There was statistical significance between SWIR otoscopy and visible otoscopy in the ability to image the promontory ($p = 0.012$) and the ossicular chain ($p = 0.010$). Increased contrast of middle ear fluid was seen in SWIR otoscopy when compared to visible otoscopy.

Conclusion: SWIR otoscopy is feasible in a pediatric population and could offer some advantages over visible light otoscopy such as better visualization of the middle ear structures through the tympanic membrane and increased contrast for middle ear effusions.

1. Introduction

Otitis media is one of the most common reasons for pediatrician visits, antibiotic prescription, and surgery in the pediatric population [1,2]. The term otitis media encompasses a variety of conditions such as acute otitis media (AOM) [3], otitis media with effusion (OME), and chronic suppurative otitis media (CSOM). These conditions are closely related and can overlap, but most importantly they are linked by presence of middle ear fluid or in the case of CSOM, fluid that drains out of the middle ear through a tympanic membrane perforation or a tympanostomy tube. While chronic suppurative otitis media is easily identifiable due to the presence of otorrhea; otoscopic diagnosis of otitis media with effusion and acute otitis media is not as straightforward [4,5]. The difficulty in identifying middle ear effusion (MEE) is largely responsible for both the over-diagnosis of cases of AOM and the frequent under-diagnosis of cases of OME [4,6].

Visible light pneumatic otoscopy is considered the best currently available diagnostic tool for otitis media [7,8]. However, pneumatic otoscopy has various limitations. The speculum must create an adequate seal against the external auditory canal to obtain tympanic membrane movement, which is seldom possible with the standard disposable speculum. Also, sufficient training is required for effective pneumatic otoscopy, but there is frequently a gap in training for most clinicians [9]. The implementation of pneumatic otoscopy by primary care physicians in their practice has not been optimal, leading to a lack of resident training and a perception that pneumatic otoscopy is difficult to master [10,11]. There is consensus that the diagnosis of MEE can be challenging and even experienced otolaryngologists require the use of adjuvant diagnostic methods such as the otologic microscope or tympanometry to better discern the presence of middle ear fluid in difficult cases [12–14].

With these challenges in mind, we have recently described an otoscope sensitive to shortwave infrared (SWIR, 1–2 μm) wavelengths of light with the objective of improving middle ear disease diagnoses [15].

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SWIR otoscopy provides two fundamental advantages over conventional visible light-based pneumatic otoscopy. First, a SWIR otoscope could help identify middle ear effusions based on the strong light absorption by middle ear fluid in the SWIR spectral region. Second, due to a longer wavelength, SWIR light can penetrate deeper through tissue, enabling a better view of middle ear anatomy behind the tympanic membrane.

The objective of this study is to present our preliminary findings evaluating the feasibility of using video rate SWIR imaging in a pediatric population with emphasis on identifying potential differences with visible light otoscopy.

2. Methods

The study was approved by the Institutional Review Board at Connecticut Children's Medical Center and the Committee on the Use of Humans as Experimental Subjects at Massachusetts Institute of Technology.

Patients 3 years of age and older seen in the otolaryngology clinic with an audiogram and tympanogram obtained within a week of the visit were recruited for the study. Ears with a tympanic membrane perforation or history of cholesteatoma surgery were excluded from the study.

Otoscopic evaluation was performed by two pediatric otolaryngologists using video otoscopy during the office visit. Consecutive videos were obtained for visible otoscopy and SWIR otoscopy. Videos for visible light otoscopy were obtained using a Macroview Welch Allyn (Skaneateles, New York) white-light otoscope adapted to a Thor Labs (Newton, New Jersey, USA) USB 2.0 CMOS 1280 × 1024 pixel, color camera and recorded in avi format. SWIR videos were recorded using a SWIR otoscope, which we have previously described in detail [15]. The system is composed of a fiber-coupled broadband light source, an otoscope head and ear speculum with a lens system to focus the reflected light onto an Indium Gallium Arsenide array detector. A filter holder in front of the sensor allows use of a variety of SWIR filters.

To determine differences between visible light otoscopy and SWIR otoscopy in the ability to identify the promontory and ossicular chain, videos were obtained with both modalities. All videos were de-identified and displayed on a 15 inch MacBook Pro for review. For each video, the otolaryngologist was asked to rate the quality of the video, ability to identify the promontory, ability to identify the ossicular chain and to determine the presence or absence of middle ear fluid. The SWIR and visible videos were not linked and videos of the same ear in both modalities were introduced at different time points.

Criteria to document absence of MEE were adequate movement of the ear drum during the office examination with pneumatic otoscopy and identifiable promontory and ossicles behind the tympanic membrane in visible and SWIR otoscopy. Criteria to document the presence of middle ear fluid included visible fluid in visible otoscopy and decreased light intensity from absorption of SWIR light by fluid in SWIR otoscopy. Results of the audiograms and tympanograms and ear examination were made available to the pediatric otolaryngologists at the time of the evaluation. Inter-rater agreement was performed using Cohen's Kappa, and Chi square analysis was used for our nominal data using SPSS 22.0 (SPSS Inc. Chicago, Illinois). Differences were considered significant for a p value < 0.05. Contrast was quantified with ImageJ software by calculating the standard deviation in signal intensity divided by the mean signal intensity for a defined region of interest within the image. The region of interest encompassed areas both with and without suspected fluid accumulation. This calculation was carried out for four video frames and averaged.

3. Results

A total of 74 ear video recordings were obtained in 20 patients (see Table 1). Eleven videos were excluded from analysis due to poor image quality for reasons including patient movement, inadequate camera integration time, or presence of cerumen limiting view of the tympanic membrane. Of the excluded videos, 7 were from SWIR imaging and 4 were from visible light otoscopy. Images were deemed adequate for interpretation in 63/74 (85.1%) of videos examined. There was no statistical significance between ability to perform SWIR otoscopy versus white light video otoscopy as indicated by a *p*-value of 0.376.

Table 1
Visible and SWIR videos collected.

Total Otoscopy Videos	74
Total Patients	20
Visible light otoscopy videos	36
SWIR otoscopy videos	38
Discarded Videos	**11**
Visible light otoscopy	4
SWIR otoscopy	7
Difference in successful image acquisition between visible and SWIR otoscopy	p = 0.376
Inter-rater Agreement	
Ability to see the Promontory	Kappa 0.81
Ability to see Ossicular Chain	Kappa 0.92
Difference between visible and SWIR otoscopy in the ability to see behind the tympanic membrane	
Ability to see Promontory	p = 0.012
Ability to see Ossicular Chain	p = 0.010
Cases of middle ear fluid present	3[a]

[a] All cases were detected with both modalities.

There was high inter-rater agreement between both examiners for identification of both the promontory and the ossicular chain with Kappa values of 0.81 and 0.92 respectively. In 8 cases, the ossicular chain was visible when using the SWIR otoscope compared to 1 case using the visible otoscope. There was improvement in the ability to see through the tympanic membrane using the SWIR otoscope. Showing statistical significance between SWIR otoscopy and visible otoscopy in the ability to image the promontory (p = 0.012) and the ossicular chain (p = 0.010) (see Fig. 1).

The three patients with presence of middle ear effusion, confirmed by pneumatic otoscopy during the otolaryngology visit, were all identified using both visible and SWIR otoscopy. An improvement in contrast using SWIR otoscopy was observed in some areas where MEE was present in the middle ear (see Figs. 2 and 3). The average contrast for visible otoscopy in the presence of middle ear effusion was 0.097 and for SWIR was 0.29.

In tympanic membranes with myringosclerosis, neither technique was able to see through areas of myringosclerosis. However, the SWIR otoscope was able to see through dried blood, dried secretions and thin dry areas of cerumen overlying the tympanic membrane (see Fig. 4).

4. Discussion

Improving primary care provider's ability to diagnose OM has an evident public health benefit [16]. AOM is often over-diagnosed due to the difficulty of confirming presence of middle ear fluid, resulting in unnecessary prescription of antibiotics thus facilitating antibiotic resistance. Meanwhile, OME is often under-diagnosed due to the asymptomatic nature of this condition and the difficulty in diagnosing MEE with traditional otoscopy [17,18]. OME is the most common reason for conductive hearing loss in the pediatric population and has been associated with behavioral and learning difficulties [19]. Recent research on cases of reversible conductive hearing loss has even identified changes that occur in the neurological pathways that persist long after the conductive hearing loss has resolved [20].

Identification of MEE using visible light otoscopy and pneumatic otoscopy has been a long standing challenge for clinicians. Despite the