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Research Paper

Otitis Media Diagnosis for Developing Countries Using Tympanic Membrane Image-Analysis

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ABSTRACT

Background: Otitis media is one of the most common childhood diseases worldwide, but because of lack of doctors and health personnel in developing countries it is often misdiagnosed or not diagnosed at all. This may lead to serious, and life-threatening complications. There is, thus a need for an automated computer based image-analyzing system that could assist in making accurate otitis media diagnoses anywhere.
Methods: A method for automated diagnosis of otitis media is proposed. The method uses image-processing techniques to classify otitis media. The system is trained using high quality pre-assessed images of tympanic membranes, captured by digital video-otoscopes, and classifies undiagnosed images into five otitis media categories based on predefined signs. Several verification tests analyzed the classification capability of the method.
Findings: An accuracy of 80.6% was achieved for images taken with commercial video-otoscopes, while an accuracy of 78.7% was achieved for images captured on-site with a low cost custom-made video-otoscope.
Interpretation: The high accuracy of the proposed otitis media classification system compares well with the classification accuracy of general practitioners and pediatricians (~64% to 80%) using traditional otoscopes, and therefore holds promise for the future in making automated diagnosis of otitis media in medically underserved populations.

1. Introduction

Otitis media (OM) is the second most important cause of hearing loss, which ranked fifth on the global burden of disease and affected 1.23 billion people in 2013 (Global Burden of Disease Study 2013 Collaborators, 2015). It is one of the most common childhood illnesses and constitutes a major chronic disease in low and middle-income countries (Global Burden of Disease Study 2013 Collaborators, 2015; World Health Organization, 2004). The incidence of OM in sub-Saharan Africa (SSA), South Asia and Oceania is two- to eight-fold higher than in developed world regions with India and SSA accounting for the majority of OM related deaths (Monasta et al., 2012; Acuin, 2004).

Common types of OM include acute otitis media (AOM), otitis media with effusion (OME), and chronic suppurative otitis media (CSOM) (Paparella et al., 1985). OM is often misdiagnosed, or not diagnosed at all, and consequently treated incorrectly which may lead to serious, or even life-threatening complications (Asher et al., 2005; Buchanan and Pothier, 2008; Legros et al., 2008).

Access to ear-, nose- and throat (ENT) specialists and equipment to diagnose OM is severely limited in developing countries (Fagan and Jacobs, 2009; World Health Organization, 2013). In Africa, for example, the majority of countries (64%) report less than one ENT specialist per million people (World Health Organization, 2013). In addition, general practitioners and pediatricians, whom are also scarce in developing countries, are often prone to under- or over-diagnose OM (Asher et al., 2005; Buchanan and Pothier, 2008; Legros et al., 2008). There is therefore a great need to develop systems that can facilitate accurate diagnosis of OM in underserved areas of the world. Kuruvilla et al. (2013) recently reported an automated algorithm based on image-analysis for distinguishing between two types of OM (AOM and OME) and middle ears without effusion with a reported accuracy of 85.61%. While these results are promising, the full range of OM types in addition to other clinical presentations such as ear canal obstructions have not been demonstrated.

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Table 1
Predefined features associated with each diagnosis (O/W — obstructing wax or foreign bodies in the external ear canal; n-TM — normal tympanic membrane; AOM — acute otitis media; OME — otitis media with effusion; CSOM — chronic suppurative otitis media with perforation).

	O/W	n-TM	AOM	OME	CSOM with perforation
Malleus bone visible	Can be either visible or not	Yes	No	Yes	Can be either visible or not
Tympanic membrane shape	Can be categorized as retracted, normal, bulging or irregular	Can be categorized as retracted, normal or bulging or irregular	Bulging	Retracted	Can be categorized as normal, bulging or irregular
Color	Pearly white	Pearly white	Predominantly red	Can be categorized as red or opaque	Pearly white
Perforation	No	No	No	No	Yes
Wax	Can be present or not	Can be present or not	Can be present or not	Can be present or not	Can be present or not
Fluid	No	No	Can be either visible or not	Yes	No
Light reflex	No	Yes	Can be either visible or not	Can be either visible or not	No

The aim of this study was to develop and validate a new image-analysis system to classify images obtained from commercial video-otoscopes into one of the following diagnostic groups: 1) obstructing wax or foreign bodies in the external ear canal (O/W); 2) normal tympanic membrane (n-TM); 3) AOM; 4) OME, and 5) CSOM with perforation. The image-analysis system was also evaluated in a clinical population using a low cost custom-made video-otoscope.

2. Methods

2.1. Development of the Image-Analysis Classification System

A decision tree was employed to classify images into one of the five diagnostic groups. In order for the tree to make an accurate diagnosis, the predefined features associated with each diagnosis (Table 1) had to be accurately identified in the images by feature extraction methods (Supplementary material 1 provides a detailed discussion on the image processing method). It included pre-processing followed by the detection of the malleus bone, tympanic membrane (TM) shape and color, perforation, obstructive wax, middle-ear fluid, and light reflex (Table 1).

Pre-diagnosed color TM photographs (n = 562) from three TM image collections captured with a range of commercially available video-otoscopes were re-evaluated independently by two experienced (>35 years of practice) specialists in otology. From them a set of 489 images (at least 500 × 500 pixels) of the TM and external ear canal were included in the study (examples provided in Fig. 1). Seventy-three images of the original 562 (12.99%) were discarded because of insufficient image quality or disagreement between the two otologists. Only images on which diagnoses were in agreement between the otologists were accepted (approximately 50% of them from children). The final set of images was classified as O/W (n = 120), n-TM (n = 123), AOM (n = 80), OME (n = 80), and CSOM with perforation (n = 86). Eighty percent of all images (n = 391) were randomly selected to develop the feature extraction algorithms and the remaining 20% (n = 98) were used for the validation study. The higher ratio for training images was used to improve classification accuracy while a proportion (20%), not used to train the system, was required for validation and testing. For each image in the training set (n = 391) the algorithms received a diagnosed image as input and analyzed the image using the feature extraction algorithms. It produced an array containing each image's features with the corresponding diagnosis as output. The decision tree was

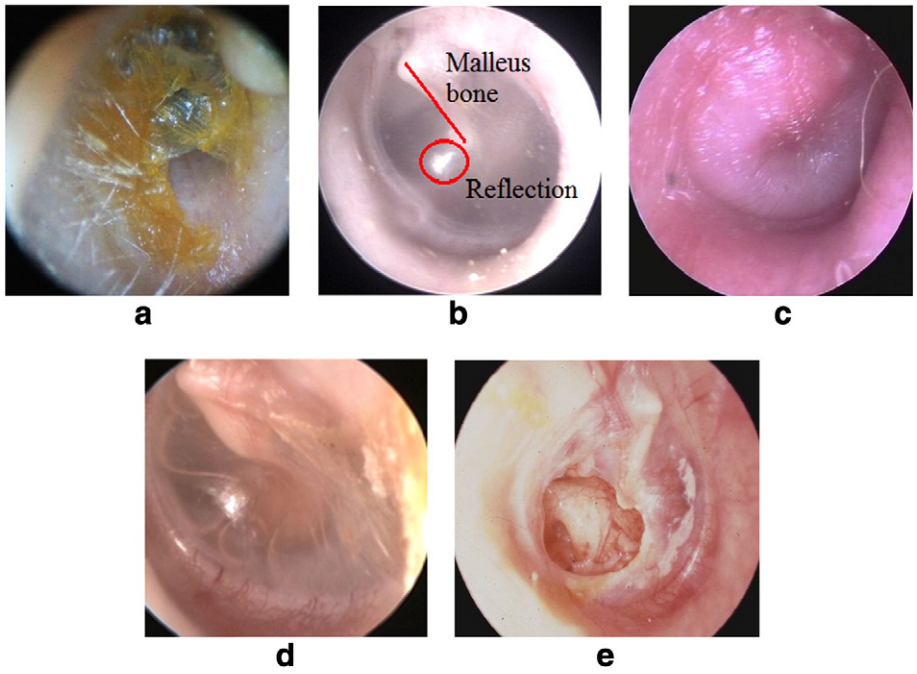

Fig. 1. Examples of the five diagnostic classification categories. a. Obstructing wax or foreign bodies (O/W) in external ear canal precluding visualization of the TM to establish an OM diagnosis; b. a normal TM (n-TM) showing a semi-transparent pearly white TM, triangular shaped light reflex and malleus bone clearly visible (red ring and line, respectively); c. acute otitis media (AOM) showing a bulging TM with red color; d. otitis media with effusion (OME) showing a retracted TM and fluid in the middle ear; e. chronic suppurative otitis media (CSOM) showing a TM perforation.
Images courtesy C. Laurent 2014.