Smartphone Otoscopy Sans Attachment: A Paradigm Shift in Diagnosing Ear Pathologies

Kranti Bhavana, MS, DNB[1], Majaz Ahmad, MBBS[1], and Piyush Sharma, MBBS[1]

Abstract

Objective. To study the validity of smartphone otoscopy.

Setting. Ear, nose, and throat (ENT) outpatient clinic of a tertiary care hospital in eastern India.

Study Design. Experimental study design to compare the efficacy of smartphone otoscopy with otoendoscopes.

Subjects and Methods. One hundred tympanic membranes (TMs) of 50 patients were examined and photographed by third-year senior residents (6 years of ENT training) using a zero-degree otoendoscope. The same 100 ears were then examined using a smartphone. Assistive light of the phone was used to illuminate the ear canal. The camera of the phone was focused to visualize and photograph the TM.

Results. Compared with the gold-standard otoendoscopes, smartphones could correctly diagnose 75% of the cases. Sensitivity and specificity of smartphone otoscopy were 87.8% and 80%, respectively. Positive predictive value was 90.6%, whereas negative predictive value was 75%. Smartphone otoscopy could correctly diagnose 88.57% of normal TMs, 86.36% of retracted TMs, and 82.85% of perforated TMs.

Conclusion. This modality of "smart otoscopy" has no added cost and can be used by most doctors after minimal training. It is an excellent teaching tool and can be used universally even in resource-limited settings.

Keywords

smartphone otoscopy, otoendoscopes, cellscopes, teleotolaryngology

Examination of the tympanic membrane (TM) is an indispensable part of routine otology practice. Ear examination has always been an equipment-based procedure. Ear, nose, and throat (ENT) physicians have been using various types of equipment to evaluate the TM. Using conventional bull's-eye lamp illumination and ear speculum to look inside the ear canal is one of the oldest methods. Joseph Toynbee first described the use of otoscopes for diagnosing ear disorders.[1] Using an otoscope, an otoendoscope, or a microscope for TM visualization has now replaced the older methods. Newer techniques have the advantage of better visualization and magnification. They are also easier to perform and hence can be done by most doctors.

The TM is the doorway to the ear. Its careful examination can provide useful information about the status of the middle and inner ear. With the advent of smartphones, taking pictures and documenting them have become very easy. Smartphones are increasingly being used to document and record outdoor office procedures such as ophthalmoscopy, otoscopy, and endoscopy. Most of these innovations have been done with iPhones after attaching accessories to the camera port.[2] This not only has made examination of patients easier for physicians but also has the potential to become a handy tool that can be used anywhere. We have truly ushered in the era of "mobile health," which has become an integral part of electronic health.[3] Widespread availability of the smartphone along with its ability to capture photos, record video and audio messages, and transfer them across long distances with ease makes it a useful tool in telemedicine too.

[1]Department of Otorhinolaryngology, All India Institute of Medical Sciences Patna, Patna, Bihar, India

Corresponding Author:
Kranti Bhavana, MS, DNB, All India Institute of Medical Sciences Patna, Patna, Bihar 801507, India.
Email: bhavana.kranti@gmail.com

Figure 1. The actual procedure used to perform smartphone otoscopy without any attachment.

Using smartphones as an educational tool to teach undergraduate and postgraduate trainees is also being explored. It has the potential to complement the conventional methods of clinical teaching. It may also be helpful in arousing the interest of the newer trainees who tend to use smartphones for almost everything!

Method

Two of the seventh-semester undergraduate students posted in the ENT department devised a method to perform otoscopy using smartphones without attaching any accessories to the camera of the phone. Here the examiner sits in front of the patient with the smartphone camera focused on the pinna of the patient. Assistive light source of the mobile phone is switched on for illumination. With minimal help from an assistant who retracts the tragus and pinna to widen the external auditory canal (EAC) opening, a full view of the pinna, EAC, and TM is obtained. On getting a full view of the TM, the picture is zoomed and photographs are taken and archived (**Figure 1**). This whole procedure can be seen in the video clip (see **Video 1**). In the case of tortuous canals, an ear speculum can be inserted for better visualization. In this study, video images were also taken for comprehensive evaluation. A close view of the TM was possible using this technique. This method does not require any attachment to the smartphone.

The technique was evaluated for its sensitivity and specificity in diagnosing ear pathologies. The images obtained with smartphones were compared with otoendoscopic pictures, which were considered the gold standard for this purpose. Ethical clearance for this study was obtained from the Institute Ethical Committee (IEC NO-96). An experimental study design as described below was adopted.

Step 1: One hundred TMs of 50 patients were examined and photographed by third-year ENT senior residents (sixth year of ENT training) using a zero-degree otoendoscope attached with an HD camera system. These images were then evaluated by another third-year senior resident of ENT (**Figures**
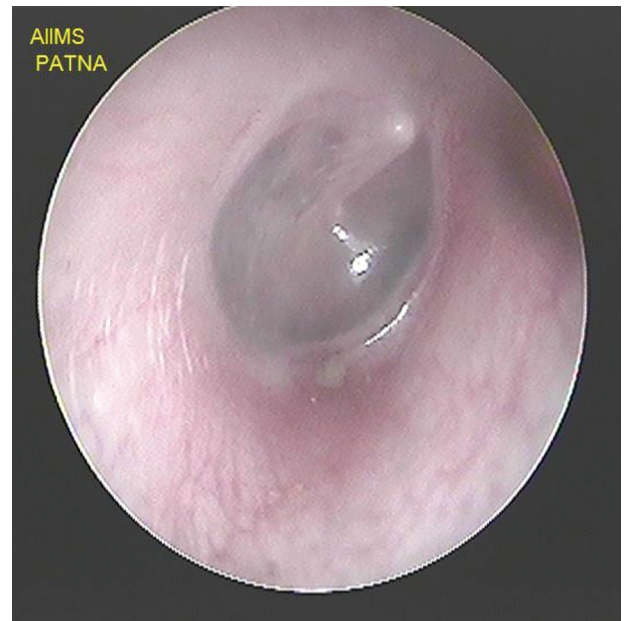

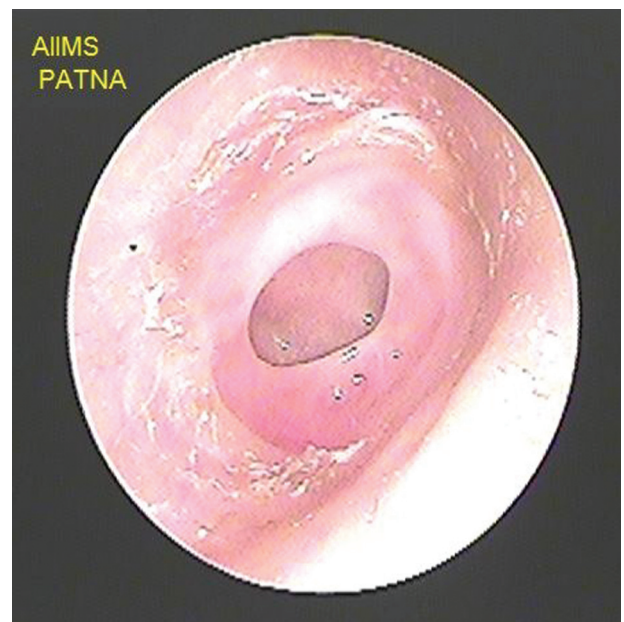**Figure 2.** Otoendoscopic picture showing normal tympanic membrane.

Figure 3. Otoendoscopic picture showing central perforation.

2 and **3**) who filled out a questionnaire based on various aspects of TM examination after evaluation of the endoscopic pictures.

Step 2: The same 100 ears were then examined by the 2 MBBS students using a smartphone. TMs were photographed using smartphones with at least a 13-megapixel camera (**Figures 4** and **5**). Assistive light of the phone was used to illuminate the ear canal. The external ear canal was slightly
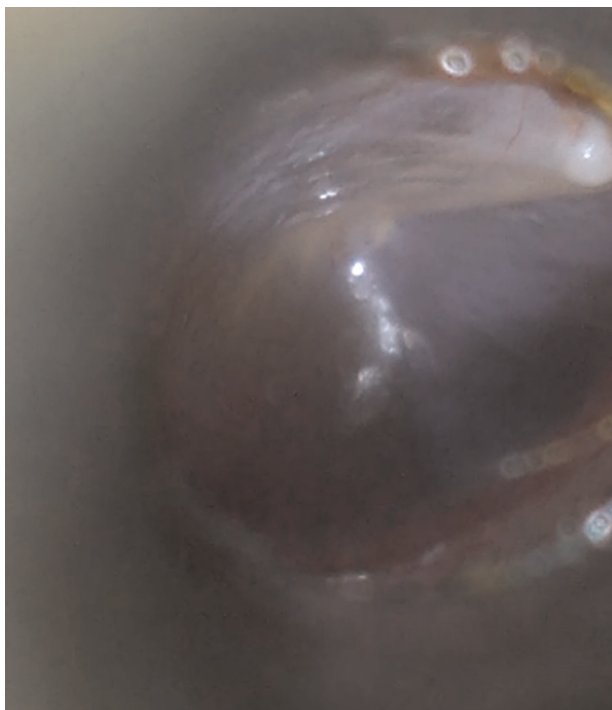
Figure 4. Same tympanic membrane as seen on smartphone otoscopy without any attachment.
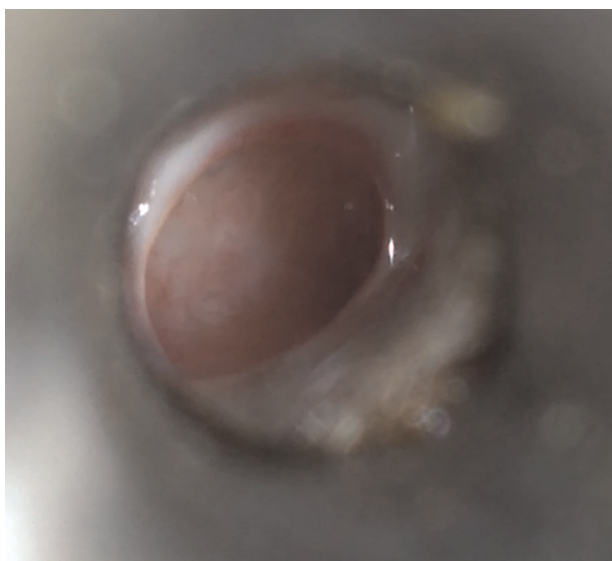

Figure 5. Same ear as seen on smartphone otoscopy (ear speculum has been used to improve visibility).

manipulated by an assistant by pulling the tragus and pinna outward to make the ear canal straight. In tortuous canals, an ear speculum was inserted for better visualization of the TM. The camera of the phone was now focused to visualize the TM. It was zoomed and pictures of the TM were taken. No attachment to the mobile phone camera or any additional light source was used. Only slight manipulation of the pinna and tragus by an

assistant and assistive light of the phone were required to take good clinical photographs of the TM (**Figures 1** and **2**). This photograph was assessed by another third-year ENT senior resident who filled out a questionnaire based on various parameters required to diagnose ear pathology. The diagnostic accuracy of ''smartphone otoscopy'' was compared with that of the otoendoscopic method using the parameters described in the following section. Statistical analysis was done and results were deduced.

Results

- **Table 1** depicts the diagnostic accuracy of the smartphone in comparison to an otoendoscope, and it shows strong agreement between the two in diagnosing normal and diseased ears (high κ coefficient). It shows high sensitivity as well as specificity in diagnosing diseased and normal ears.
- **Table 2** shows overall agreement in diagnosis by smartphone and otoendoscopy. The κ coefficient shows strong agreement between smartphones and otoendoscopy in diagnosing both external and middle ear pathologies.
- **Table 3** shows the efficacy of smartphone in visualizing the external auditory canal and TM.
- The TM was appreciable in 88% of the cases using a smartphone in comparison to 93% using an otoendoscope. There was no statistically significant difference observed between the 2 devices for identifying the TM. Using a smartphone, the pars flaccida was seen in 40% of cases, and the attic could be visualized in 25% of cases only.
- Cone of light could be appreciated in 37 cases (39.8%) using an otoendoscope, whereas it could be appreciated in 33 cases (37.5%) using a smartphone. Average time of diagnosis using this technique was 1 to 2 minutes (31%). For all the cases, the residents strongly agreed that the otoendoscope provided adequate light for examination. In the case of the smartphone, 73% agreed, 22% strongly agreed, 4% neither agreed nor disagreed, and 1 disagreed that the device provided adequate light for examination.
- On statistical analysis, it is evident that this technique of smartphone otoscopy without the use of any accessories attached to the phone can be used to diagnose ear pathologies in 75% of cases in comparison to the gold standard. This basic tool can thus be used by most medical practitioners to perform otoscopy to form an initial diagnosis with minimal training. This study was done using a basic android phone with ≥13-megapixel camera. Since no extra light source or any camera attachment is used, there is no added cost to this technique. It can be used even in resource-limited settings by most medical professionals at least to form the initial diagnosis.

Table 1. Diagnostic Accuracy of Smartphone Compared With Otoendoscope.[a]

Characteristic	Diagnostic Index (95% CI)			
	Diseased vs Normal Ear	Perforated TM	Retracted TM	Normal TM
Sensitivity	87.8 (77.51-94.62)	82.35 (65.47-93.24)	63.63 (40.66-82.80)	77.42 (58.90-90.41)
Specificity	80.0 (61.43-92.29)	98.11 (89.93-99.95)	81.53 (69.97-90.08)	85.71 (73.78-93.62)
Positive predictive value	90.6 (82.45-95.21)	96.55 (79.77-99.49)	53.85 (39.02-68.02)	75.0 (60.57-85.42)
Negative predictive value	75.0 (60.46-85.80)	89.66 (80.73-94.72)	86.89 (79.02-92.10)	82.27 (77.98-92.99)
κ coefficient	0.667 (0.507-0.826)	0.826 (0.704-0.949)	0.426 (0.216-0.636)	0.627 (0.456-0.797)

Abbreviations: CI, confidence interval; TM, tympanic membrane.
[a]The table shows strong agreement between the smartphone and the otoendoscope in diagnosing normal and diseased ears (high κ coefficient). It shows high sensitivity as well as specificity in diagnosing diseased and normal ears.

Table 2. Overall Agreement in Diagnosis by Smartphone and Otoendoscopy.[a]

Smartphone	Otoendoscope, No.						
	CSOM	ASOM	Retracted	Normal	Wax	Otomycosis	Total
CSOM	31	1	0	0	0	0	32
ASOM	1	0	0	0	0	0	1
Retracted	5	0	14	6	0	1	26
Normal	1	0	6	24	0	1	32
Otomycosis	0	0	0	0	0	0	0
Total	38	1	21	30	3	3	96

Abbreviations: ASOM, acute suppurative otitis media; CSOM, chronic suppurative otitis media.
[a]The κ coefficient shows strong agreement between smartphones and otoendoscopy in diagnosing both external and middle ear pathologies. Unweighted κ coefficient (95% confidence interval) = 0.644 (0.526-0.763). Weighted κ coefficient (95% confidence interval) = 0.764 (0.673-0.853).

Discussion

This study was aimed to evaluate the feasibility of using smartphones for routine examination of the TM and the external ear. The images obtained by this technique were compared with the images obtained by otoendoscopy using a 0-degree endoscope. Two different sets of ENT specialists diagnosed the ear condition on the basis of the images obtained by the 2 methods, and a comparison was made. ENT specialists who were involved in examination and diagnosis of ear pathology were third-year ENT senior residents who had already completed their 3 years of basic ENT training and now were in their sixth year of ENT practice. They were thus fully trained to make otological diagnoses. It was done in 50 patients in the outpatient clinic of a tertiary hospital. A unique feature of this technique is the absence of any attachment to the phone camera for taking pictures of the TM and using only assistive light source of the phone as the illuminating agent. Minimal assistance by one person was required to straighten the ear canal. Good still as well as video images can be taken using this method.

Smartphone-enabled otoscope (SEO) was compared with microscopic otoscopy in the detection and evaluation of TM pathology in an otology/neurotology practice by Moshtaghi et al.[2] Here they used an attachment to the smartphone camera. They concluded that SEO is 96% specific in

identifying normal TMs and 100% sensitive in identifying pathology. Its 97% positive predictive value and small false-positive rate make it a useful screening tool. They used a "cellscope," which is an attachment to iPhones and is available at a cost.

Our technique of doing otoscopy using a smartphone without any attachment to the camera yields a sensitivity and specificity of 87.8% and 80%, respectively, in diagnosing ear pathologies. Positive predictive value was 90.6%, whereas negative predictive value was 75%. This is obviously lower than SEO but, as mentioned above, has no added cost like that of a cellscope. It can be performed using all kind of smartphones with a good camera (preferably 13 or more megapixels).

The main limitation of this technique was difficulty in examining ear canals of pediatric patients as their canals are often very narrow. The pars flaccida was difficult to visualize without using ear speculums, and it can be a challenging process for untrained medical professionals to diagnose attic diseases. Some further modifications like using special small-sized speculums for pediatric ear canals may be needed to overcome these limitations. As far as external ear canal pathologies like wax and otomycosis were concerned, there was strong agreement between diagnosis by otoendoscopes and smartphones (weighted κ value = 0.764 showing good strength of agreement). Hence, a smartphone without

Table 3. Efficacy of Smartphone in Visualizing the External Auditory Canal and Tympanic Membrane.

Parameter	External Auditory Canal, %	Tympanic Membrane, %
Excellent	36	17
Very good	39	37.5
Good	22	30.7
Poor	3	3.4

any attachment can be a good tool to diagnose external ear canal pathologies, as well.

This technique of ''smart otoscopy'' could find its usage in various circumstances, especially in the developing world, where access to health care equipment can be a limiting factor. Even for undergraduate teaching, it is difficult to provide otoscopes and otoendoscopes to all the students. Smartphones, due to their universal availability, can be used not only for their clinical utility but also for teaching and learning. Phone otoscopy could be taught to patients and/or their caretakers so they could easily contact their primary doctors with the findings if they had ear problems. It could be used in the same way for follow-up after ear surgery. Further studies need to be undertaken to evaluate the feasibility of this technique for this purpose.

Smartphones are an excellent tool for telemedicine.[4-6] Telemedicine extends the accessibility of general and specialized health care providers to rural areas and can improve patient satisfaction and health care–related expenses.[7,8] Its use as a diagnostic tool has immense utility in the Indian scenario, which still lacks a robust health care system, especially in its rural areas. Unlike mobile phones, which have found a place in every person's pocket today, health care is still a far cry for a sizable proportion of the population. Currently, most ENT surgeons are located in tier 1 or tier 2 cities of India. Rural India is mostly outside their purview. As a result, ENT diseases are often neglected. Even primary care physicians in these areas barely do an otoscopic examination. Inability to establish the diagnosis leads to high numbers of hearing-impaired individuals. These patients have preventable causes of hearing loss but, due to lack of proper diagnosis and care, end up having irreversible hearing loss. Empowering these primary care physicians with smartphone otoscopy can revolutionize ENT care in India. It could enable them to diagnose common ear conditions and consult their ENT colleagues for difficult cases by sharing mobile pictures on various photo-sharing applications.

Using a smartphone-enabled otoscope for resident training has been explored in a few countries.[2,9] Using ear simulators and video otoscopy to improve medical training in this field has been used by educators.[10,11] These smartphone-enabled otoscopes (cellscopes) come with some cost and may not be used by many students readily. Medical universities in India are not very well equipped with equipment for ENT undergraduate teaching. The number of undergraduate students far exceeds the number of equipment available in clinics for examination of

ENT patients. Otology remains a challenge for them as they do not get enough otoscopes to examine the ear. Inability to see the TM can have deleterious effects on their learning. A smartphone, on the other hand, is available to almost every student. Hence, this technique of using smartphones for otoscopy without any attachment comes with no added cost. It can be used easily by students and physicians in all settings. This can increase their learning experience manifold.

Conclusion

This technique of using the smartphone for otoscopy without any attachment to its camera is a very cost-effective method. It can be performed in resource-constrained settings with minimal assistance from another person and takes very good pictures of not only the TM but also of the pinna and the external auditory canal. It is an excellent tool for ENT teaching and has immense scope in tele-otolaryngology. The technique described is easy to learn, has no added cost, and can be performed by anyone, hence making it a good tool for routine diagnosis of ear pathology.

Author Contributions

Kranti Bhavana, principal investigator, planning and executing the project, and writing the manuscript; **Majaz Ahmad**, performing the procedure, helping with data collection and statistical analysis, and helping in writing the manuscript; **Piyush Sharma**, performing the procedure, helping with data collection and statistical analysis, and helping in writing the manuscript.

References

1. Mudry A. References in the history of otology: the importance of being earnest. *Otol Neurotol.* 2007;28:135-140.
2. Moshtaghi O, Sahyouni R, Haidar YM, et al. Smartphone-enabled otoscopy in neurotology/otology. *Otolaryngol Head Neck Surg.* 2017;156:554-558.
3. Jones WS. Video otoscopy: bringing otoscopy out of the ''black box.'' *Int J Pediatr Otorhinolaryngol.* 2006;70: 1875-1883.
4. Ephraim RK, Duah E, Cybulski JS, et al. Diagnosis of *Schistosoma haematobium* infection with a mobile phone-mounted Foldscope and a reversed-lens CellScope in Ghana. *Am J Trop Med Hyg.* 2015;92:1253-1256.
5. Chang J, Arbeláez P, Switz N, et al. Automated tuberculosis diagnosis using fluorescence images from a mobile microscope. *Med Image Comput Comput Assist Interv.* 2012;15:345-352.

6. Coulibaly JT, Ouattara M, D'Ambrosio MV, et al. Accuracy of mobile phone and handheld light microscopy for the diagnosis of schistosomiasis and intestinal protozoa infections in Côte d'Ivoire. *PLoS Negl Trop Dis*. 2016;10:e0004768.

7. Mair F, Whitten P. Systematic review of studies of patient satisfaction with telemedicine. *BMJ*. 2000;320:1517-1520.

8. Roine R, Ohinmaa A, Hailey D. Assessing telemedicine: a systematic review of the literature. *CMAJ*. 2001;165:765-771.

9. Sahyouni R, Moshtaghi O, Rajaii R, et al. Evaluation of an iPhone otoscope in a neurotrauma clinic and as an adjunct to neurosurgical education. *Insights Neurosurg*. 2016;1:4.

10. Morris E, Kesser BW, Peirce-Cottler S, Keeley M. Development and validation of a novel ear simulator to teach pneumatic otoscopy. *Simul Healthc*. 2012;7:22-26.

11. Chen J, Lieffers J, Bauman A, Hanning R, Allman-Farinelli M. The use of smartphone health apps and other mobile health (mHealth) technologies in dietetic practice: a three country study. *J Hum Nutr Diet*. 2017;30:439-452.