

Expanding the Capacity of Otolaryngologists in Kenya through Mobile Technology

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Abstract

Objective. To determine if reliable, objective audiologic data can be obtained by nonotolaryngology and nonaudiology practitioners using novel mobile technology in an effort to expand the capacity for early identification and treatment of disabling hearing loss in the developing world.

Study Design. Cross-sectional, proof-of-concept pilot study.

Setting. Screenings took place during an annual 2-week otolaryngology surgical mission in October 2016 in semirural Malindi, Kenya.

Subject and Methods. Eighty-seven patients (174 total ears) were included from 2 deaf schools (n = 12 and 9), a nondeaf school (n = 9), a tuberculosis ward (n = 8), and a walk-in otology clinic at a local hospital (n = 49). An automated, tablet-based, language-independent, clinically validated, play audiometry system and wireless otoscopic endoscopy via an iPhone or laptop platform was administered by Kenyan community health workers (CHWs) and nursing staff.

Results. Various degrees of hearing loss and otologic pathology were identified, including 1 child presumed to be deaf who was found to have unilaterally normal hearing. Other pathology included 2 active perforations, 2 healed perforations, 2 middle ear effusions, and 1 cholesteatoma. CHWs and nursing staff demonstrated proficiency performing audiograms and endoscopy. Patients screened in a deaf school were more likely to complete an unreliable audiogram than patients screened in other settings ($P < .01$).

Conclusion. This study demonstrates the feasibility of a non-otolaryngology-based hearing screening program. This may become an important tool in reducing the impact of hearing loss and otologic pathology in areas bereft of otolaryngologists and audiologists by allowing CHWs to gather important patient data prior to otolaryngologic evaluation.

Keywords

global health, public health, low- and middle-income countries, endoscopic otoscopy, mobile technology, iPad audiometry, hearing screening, community health workers

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The vast majority (80%) of disabling hearing loss is found in low- and middle-income countries (LMICs).¹ Unfortunately, the countries with the highest burden of hearing loss are often those least able to help patients accommodate to their disability.² In these regions, early identification and treatment are of the utmost importance, as deafness can cause significant functional impairment in the ability of these individuals to contribute productively to society.² Sub-Saharan Africa, unfortunately, has very limited otolaryngology and audiology capacity.³ In Kenya specifically, there are 1.2 otolaryngologists and 0.12 audiologists per 1,000,000 people, respectively.² The United Kingdom's (UK's) National Health System is designed to apportion health care providers according to census data. As such, there are 10 otolaryngologists and 41 audiologists in practice per 1,000,000 people in the UK.³ Extrapolating these figures, Kenya has just 12.1% and 0.3% of the capacity of otolaryngologists and audiologists, respectively, compared with an appropriately proportioned developed country. Shortages of otolaryngology and audiology services

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in Kenya and other LMICs pose challenges to early identification and treatment of otologic pathology.⁴

Despite having limited access to hearing health care providers, Kenya, like many LMICs, has a surprisingly robust telecommunications infrastructure.⁵ In fact, an estimated 88% of Kenyan adults have a cellphone and 81% have access to the Internet.^{6,7} These numbers, which are only increasing, have allowed e-Health and m-Health platforms to play a significant role in expanding the capacity of health care providers in LMICs.^{5,8,9}

In an effort to expand the capacity for otolaryngologists and audiologists to identify treatable hearing loss, we piloted a novel, presurgical screening tool designed to be conducted by nurses and nonmedical staff with minimal training using existing infrastructure (mobile and Internet technology). The screening tool consisted of a 2-armed system employing a tablet-based play audiometry and otoscopic endoscopy to record dual objective measures that can be used by otolaryngologists to determine patient candidacy for audiologic (ie, preferential classroom seating, hearing aids) or surgical intervention. The program was designed to be simple, portable, language independent, and cost-effective to optimize it for use in low-resource settings. This study tests the feasibility of the aforementioned screening program in multiple health care settings.

Methods

Study Design

A cross-sectional hearing screening program was used to assess patients across a variety of settings in semirural Malindi, Kenya. Screenings took place during an annual 2-week head and neck surgical mission in October 2016. Participants underwent a formal audiometric evaluation and otologic endoscopic examination. Local Kenyan nurses, community health workers (CHWs), and nongovernmental organization volunteers were trained and completed the audiograms and examinations. Exams were performed by local staff primarily without assistance unless assistance was required, in which otolaryngology training staff were available to troubleshoot.

Data were collected and organized using Microsoft Excel (Redmond, Washington, USA). Basic statistics were completed using IBM SPSS Statistics for Macintosh Version 24 (Armonk, New York, USA). Categorical variables were analyzed using a χ^2 test. This study was financially supported by a voucher grant from the Vanderbilt Institute for Clinical and Translational Research. Further funding was obtained from the American Academy of Otolaryngology—Head and Neck Surgery Foundation Humanitarian Grant (A.D.L.J. and C.N.K. were recipients). This study was reviewed by the Vanderbilt University Medical Center Institutional Review Board (IRB) as IRB exempt because of minimal risk to the subjects. Verbal consent was obtained from all participants prior to proceeding, and all recorded data were deidentified.

Subjects

Patients were recruited from multiple locations. The walk-in clinic at Tawfiq Muslim Hospital (TMH) in Malindi,

Kenya, was advertised with flyers in the community as well as by word of mouth. Screenings also took place in three schools, 2 of which serve deaf students (Gede Special School for the Deaf and the Kakayuni Special School for the Deaf) and 1 that serves nondeaf students (Gede Primary School). Local schools were contacted in advance to identify students who would benefit from audiometric evaluation. Three children from the Silali Special School traveled to TMH and participated in the walk-in clinic at TMH. In addition, 8 patients from a local tuberculosis (TB) ward traveled to TMH for screenings to monitor for ototoxicity. Participants who expressed discomfort with audiometric evaluation or otologic examination were excluded.

Screening Process

Each participant underwent otologic examination and screening audiometric evaluation. Prior to screening, each participant underwent a brief otoscopic examination to ensure the presence of a patent external auditory canal. Patients with cerumen impaction underwent a limited cerumen removal prior to endoscopic examination and audiometric evaluation. Endoscopic images of the tympanic membrane were captured using either a wireless otoscope (Firefly Global DE550, Palo Alto, California, USA) or a smartphone-enabled otoscope (Cellscope, San Francisco, California, USA; **Figure 1**). Smartphone-otoscopy images were captured with and stored on an iPhone 6 (Apple, Cupertino, California, USA) using *Cellscope-Oto for Clinicians* software (Cellscope). Wireless otoscopy images were captured with a Firefly DE550 wireless otoscope (Firefly Global) and stored on a 32-Gb HP Stream laptop (Hewlett Packard, Palo Alto, California, USA). Costs of equipment used are described in **Table 1**. Of note, Shoebox and Firefly Global offer humanitarian discounts for select cases beyond what is quoted in **Table 1**. Patients from the TB ward underwent audiometric evaluation but were excluded from otologic endoscopy to prevent possible equipment contamination.

Audiometric evaluation was conducted using an automated, language-independent, clinically validated, play audiometry system (Shoebox Professional Audiometer by Clearwater Clinical, Ottawa, Ontario, Canada) on an iPad Mini 2 tablet (Apple; **Figure 2**). “Play audiometry” is presented to the patient as a game in which the participant indicates whether he or she can hear a presented sound. Sounds are played at various frequencies with increasing decibel (dB) intensity via a modified Hughson-Westlake method in an increasing-decreasing fashion until the correct threshold is determined. Silent cues are presented at random to ensure participant understanding and compliance with the test. Continuous, frequency-specific background noise is monitored during the test, and tones presented during times of increased background noise are repeated. Unmasked pure-tone air and bone-conduction thresholds were performed using a calibrated TDH-50 air transducer and a B-81 bone transducer (Clearwater Clinical). Participants who self-reported normal hearing underwent a screening audiogram



Figure 1. iPhone-based otoscopy (A) and laptop-based wireless endoscopic otoscopy (B) were used to capture tympanic membrane pathology.

Table 1. Cost for Equipment Used during the Hearing Screening Program.

Product	Cost
Shoebox Professional	\$4100
Shoebox Concierge	\$600
Firefly Wireless Endoscope (DE550)	\$399
Cellscope Oto	\$299

(thresholds limited to 500 and 2000 Hz). If found to have a deficit, or in cases of self-reported hearing loss, participants underwent diagnostic evaluation (thresholds tested included 500, 1000, 2000, and 4000 Hz). Pediatric participants were guided through the test by a trained provider. Adult participants received instructions on how to use the application and self-administered the testing under supervision of local trained providers. All audiometric testing was completed in a quiet room. Audiograms were automatically encrypted, saved locally on the tablet, and uploaded to a secure Internet backup during WiFi availability. Patients were assigned a unique medical record number to match their audiograms to their endoscopic images.

Outcomes

Audiogram results were categorized into mild (30-40 dB), moderate (41-60 dB), severe (61-80 dB), and profound (≥ 80 dB) hearing loss. Ambient room noise prohibited accurate measurements less than 30 dB. Hearing loss was further categorized into sensorineural hearing loss (SNHL), conductive hearing loss (CHL), and mixed hearing loss. If a patient provided consistent affirmative responses in the absence of a tone, the audiogram was automatically deemed unreliable by the software. Unreliable audiograms were excluded. Otoscopic images were reviewed by both A.D.L.J. and C.N.K. and classified as normal, cerumen impaction, active perforation, healed perforation, possible

cholesteatoma, and granulation tissue. Discrepancies between A.D.L.J. and C.N.K. were resolved by J.L.N.

Results

One hundred seventy-four ears ($n = 87$ patients) were tested in 5 different settings (**Table 2**), including 2 deaf schools ($n = 12$ and 9; Gede Special School for the Deaf and the Kakayuni Special School for the Deaf), a nondeaf school ($n = 9$; Gede Primary School), patients from a TB ward ($n = 8$), and a walk-in otology clinic at TMH ($n = 49$).

Of patients tested, 17 had unreliable audiograms. Most (65%, 11/17) unreliable audiograms were obtained from patients screened in deaf schools (**Table 3**). In fact, patients screening in a deaf school were more likely to complete an unreliable audiogram than patients screened in other settings ($P < .01$). Deaf children demonstrated poor understanding of the play audiometry application despite sign language explanations provided by their teachers. Only patients with reliable audiograms ($n = 70$) were included in the following descriptive statistics (**Table 2**).

Three of nine (33%) children in the nondeaf school (Gede Primary School) had mild SNHL; the remainder of children screened had normal hearing. Most (73%; 8/11) patients from the 2 deaf schools were found to have severe-to-profound SNHL. Notably, 1 patient in the deaf school had unilaterally normal hearing, 1 had only mild SNHL, and another had moderate SNHL. Of patients from the TB ward, 50% (4/8) had normal hearing and 50% (4/8) had moderate SNHL.

Patients who presented to the walk-in clinic at TMH presented with a variety of otologic complaints and had subsequently variable audiogram results. Sixteen patients (38%) presented with normal hearing, 19 (45%) had SNHL, and 7 (17%) had CHL (**Table 2**).

Otosopic examination revealed various patients with abnormal tympanic membrane pathology. One patient presented with a large, unilateral nasopharyngeal mass and was found to have a serous effusion with associated conductive hearing loss (**Figure 3**). Two ears revealed healed perforations, and 2 ears demonstrated active perforations. One cholesteatoma was



Figure 2. iPad audiometry can be administered by either the patient (A) or an assistant (B), in the case of a child.

Table 2. Severity of Hearing Loss by Screening Site.^a

Degree of Hearing Loss by Site	Normal	Mild	Moderate	Severe	Profound	Total
Gede Primary School	6	3	0	0	0	9
Gede Special School for Deaf	1	1	1	5	0	8
Kakyuni Speical School for Deaf	0	0	0	1	2	3
Tawfiq Hospital walk-in clinic	16	8 ^b	11 ^b	4	3	42
Tuberculosis ward	4	0	4	0	0	8
Total	27	12	16	10	5	70

^aExpectedly, deaf schools had more severe to profound hearing loss than nondeaf settings.

^bOf note, 8 patients at Tawfiq walk-in clinic had conductive hearing loss (1 mild, 7 moderate). No other sites reported conductive hearing loss.

Table 3. Characteristics of Patients Obtaining Unreliable Audiograms.^a

Setting	Reliable Audiograms	Unreliable Audiograms	Total
Patients from deaf schools			
Gede Special School for the deaf	3	6	9
Kakayuni Special School for the deaf	8	4	12
Total screened from deaf schools	11	10	21*
Patients screened in other settings			
Tawfiq Muslim Hospital walk-in clinic	42	7	49
Gede Primary School	9	0	9
Tuberculosis ward	8	0	8
Total screened in other settings	59	7	66*

^aPatients screened in deaf schools were more likely to complete an unreliable audiogram than patients screened in other settings; * $P < .01$.

identified. There were no discrepancies noted between A.D.L.J. and C.N.K. in interpreting otoscopy results.

Discussion

The global burden of disabling hearing loss is overwhelming, with eastern Asia, southern Asia, and Sub-Saharan Africa most significantly affected.² In Sub-Saharan Africa, the calculated deficits of otolaryngologists and audiologists when compared with UK service ratios are 4669 and 20,406, respectively.⁴ This proof-of-concept study suggests

that basic otologic and audiologic data can be captured by individuals without formal otolaryngology or audiology training, thus shifting the burden away from already overwhelmed health care providers. Inferences about the incidence and prevalence of hearing loss and otologic pathology in rural Kenya are outside of the scope of this study.

Given the relative paucity of hearing health care providers and the growing number of CHWs, the path moving forward should foster development of programs that use our CHW colleagues. It is estimated that there are more than 1

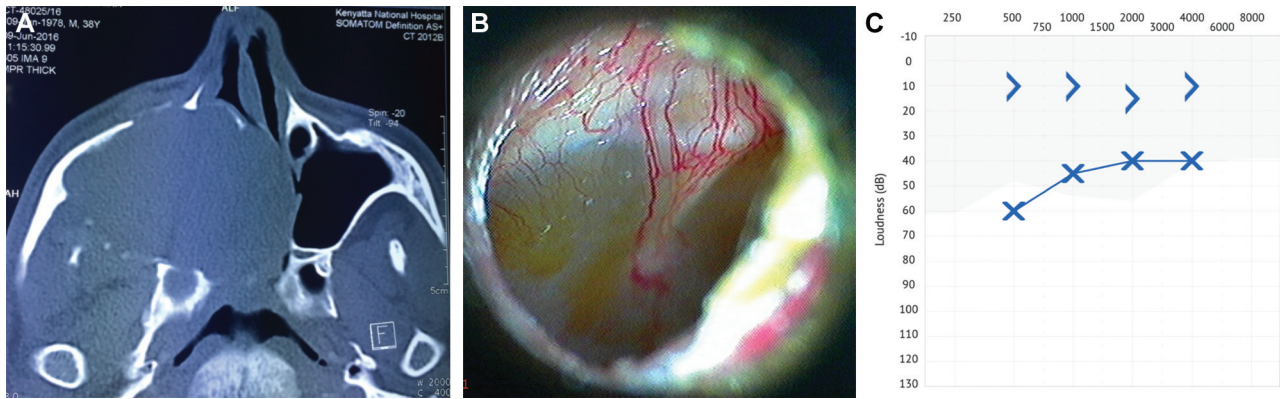


Figure 3. This 38-year-old man presented with a large, unilateral nasopharyngeal mass (A) and a unilateral serous effusion (B) with a conductive hearing loss (C).

million paid CHWs in Asia and Sub-Saharan Africa.¹⁰ Many of these CHWs are using mobile technology to expand their reach in LMICs.¹¹ In fact, several of our colleagues in other surgical subspecialties have capitalized on mobile technology use among CHWs. Ophthalmologists are using CHWs to gather vision screening data using smartphone technology.¹²⁻¹⁴ The African Tele dermatology Project has CHWs store and forward suspicious cases on a smartphone to expert dermatologists for diagnosis.¹⁵ Orthopaedic surgeons and urologists are using smartphone technology to teach best-practice surgical techniques to those in the LMICs.^{16,17} Although both tablet play audiometry and wireless endoscopic otoscope systems have been clinically validated in both high- and low-resource settings, to our knowledge, this is the first CHW-based program in the field of otolaryngology in LMICs.¹⁸⁻²³

Although CHW-based programs such as this can serve to reduce some of the clinical burden of otolaryngologists in LMICs, a number of barriers still exist. First, our pilot program uses multiple platforms (laptop, smartphone, and tablet), which is cumbersome for a CHW to collect efficiently. The ideal platform would collect both audiograms and otoscopy on the same interface, which would eliminate extra steps in organizing the data collected. Second, no existing audiogram application effectively accounts for ambient noise, which can cause falsely positive hearing screening failures in noisy settings. In addition, no audiogram platform accounts for children who are unable to participate in traditional audiometry (developmentally delayed and children younger than 4-5 years). The ideal platform would also include otoacoustic emissions or automated auditory brainstem responses to capture prelingual children to optimize the effectiveness of the intervention. In addition, bone-conduction measurements are limited as they are not available with masking in the play audiometry mode. Therefore, the ability of a CHW to gather information regarding CHL versus SNHL is limited, as masked bone conduction is not available in an automated, easy-to-use format.

Despite testing only iPad-based audiometry, we did not find that the features of an iPad (larger screen size, storage space, etc) provided an essential advantage that would make

having an iPad, as opposed to a mobile phone or laptop, an essential component to a CHW-based hearing screening program. Smartphone-based audiometer applications have been recently released and are available for lower cost (HearX Premium, \$899) than iPad audiometry. As this hardware was released after our study concluded, the HearX Premium was not tested during our pilot. This study has established that CHW-based hearing screening is feasible; however, further testing should be completed regarding the efficacy of newer alternate mobile audiology platforms.

Establishing the efficacy of a CHW to gather basic objective audiologic and otoscopic data can have a significant impact on the number of patients an otolaryngologist in a low-resourced setting can treat. In these settings, audiologists are even more rare than otolaryngologists, which makes audiograms very valuable. Adding reliable audiograms and otoscopic data to a patient's chart prior to an initial visit with an otolaryngologist can allow a provider to appropriately screen patients to increase the likelihood of identifying patients with surgically treatable pathology. Therefore, a CHW-based hearing screening program can significantly augment an otolaryngologist practicing in a low- and middle-income country.

Otolaryngology in LMICs has 2 main players: local otolaryngologists and international otolaryngologists who participate in surgical and educational service work. Telemedicine programs such as this can bridge the gap between these 2 groups. Future implications include the ability for surgical mission trips to understand the pathology of the patients they will treat prior to their arrival. In addition, this program will allow local otolaryngologists to communicate with international surgeons regarding questions that may emerge during postsurgical follow-up. This program will need to be trialed in other countries prior to broader conclusions being drawn about the use of CHW-centered telemedicine in otolaryngology.

Conclusion

This study highlights the utility of a CHW-based screening tool to identify and document audiometric evaluations and otologic endoscopic examinations. The combination of these 2 objective measures may identify candidates for hearing

aids or otologic surgery and may help treat hearing loss in areas bereft of audiologists and otolaryngologists.

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Author Contributions

Asitha D. L. Jayawardena, study design, implementation/execution, data analysis, manuscript creation; **Charissa N. Kahue**, study design, implementation/execution, data analysis, manuscript editing; **Samantha M. Cummins**, data analysis, manuscript editing; **James L. Netterville**, Study design, implementation/execution, manuscript editing.

Disclosures

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