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Pediatric hearing screening in low-resource settings: Incorporation of video-otoscopy and an electronic medical record

Kristen L. Yancey[a,*], Loyce J. Cheromei[b], Jackie Muhando[c], Jim Reppart[d], James L. Netterville[a], Asitha D.L. Jayawardena[a]

[a] Department of Otolaryngology, Vanderbilt University Medical Center, Nashville, TN, 37232, USA
[b] Malindi District Hospital, Malindi, Kenya
[c] Tawfiq Hospital, Malindi, Kenya
[d] Caris Foundation Kenya, P.O. Box 1965, Malindi, Kenya

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ABSTRACT

Objective: To develop a sustainable, comprehensive, intervention-based approach to pediatric hearing care in low- and middle income countries (LMICs) where global hearing loss is most heavily concentrated.

Methods: Community health workers (CHWs) in Kilifi county, Kenya were trained to conduct hearing screening and video-otoscopy via a unified, smartphone-based platform using mobile electronic medical record (EMR) generation for children diagnosed with hearing loss or other pathology. Among at-risk students pre-selected by their teachers, the frequency of hearing loss and pathology in children with and without hearing loss was measured.

Results: Of the 155 screened, 16 (10%) children were found to have hearing loss. 12 (5.9%) children with normal hearing had the following pathology: perforation (N = 5 ears), effusion (N = 9), retraction (N = 6), and infections (N = 7). CHWs were also adept at EMR creation without significant delay in workflow. Out of all those screened, 28 (18%) children were found to have hearing loss or other pathology and were referred to follow up. All 28 of 28 children referred were successfully entered into the EMR.

Conclusions: CHWs with little to no prior medical experience can provide a much needed public health service - hearing screening in LMICs where access to health care is limited. The incorporation of video-otoscopy provides a more comprehensive approach to hearing care by not only helping identify etiologies of existing hearing disability but also conditions that predispose to future hearing loss. It can easily be performed in conjunction with hearing screenings via the use of a unified, mobile platform. The addition of EMR supports follow-up and allows remote consultation.

1. Introduction

Hearing loss affects 466 million worldwide, with a prevalence of 6.1% and rising [1]. The implications for speech, language, educational attainment, employment opportunities and future earning potential are devastating [2]. The impact of this disability extends beyond the individual to the community and even national level [2]. Hearing-attributable disability and associated costs can be ameliorated in part by timely intervention [2]. The early identification of hearing loss is therefore needed through cost-effective screening programs (Table 1).

Approximately 34 million children suffer from at least a moderate hearing loss, with a majority from low- and middle-income countries (LMICs) [1]. Most pediatric hearing loss is preventable, and there is a global need for further public health policy and resources directed towards increasing vaccination, detecting and treating infections, and decreasing use of ototoxic medications [3]. Untreated recurrent otitis media (OM) risks future hearing impairment [4], in part from the development of chronic suppurative otitis media (CSOM) - a leading cause of pediatric hearing loss in LMICs [5]. While acute and recurrent OM is often managed with antibiotics or minor procedures, the sequelae of CSOM are more likely to require complex surgery that is rarely available in LMICs [6].

Our team previously piloted a community health worker (CHW) driven hearing screening program in Kenya [7] and Haiti [8]. To date, over 600 children have been screened. However, as each child with a correctable hearing loss is identified, the need for a streamlined record

* Corresponding author. Vanderbilt University Medical Center, Department of Otolaryngology-Head and Neck Surgery, 7209 Medical Center East-South Tower, 1215 21st Avenue South, Nashville, TN, 37232-8605, USA.

E-mail addresses: kristen.yancey@vumc.org (K.L. Yancey), kenya@carisfoundation.org (J. Reppart).

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Table 1

Comparison of portable, automated audiometry clinically validated in peer-reviewed literature and portable video-otoscopy devices currently available. Prices up to date as of November 27, 2018.

	Key Features	Pricing (USD)	Intended Age	Additional Required Hardware	Compatibility
Audiometry					
AudCal[l] [34]	- Disclaimer: not intended to be diagnostic - standard calibration not possible - no screening feature	Free	Adults	Smartphone, tablet, iPhone headphones	iOS
EarTrumpet[m] [35]	- diagnostic - automated masking - standard calibration not possible - no screening feature	3.99	Adults	Smartphone, headphones	iOS, Android
HearX[n] [11,14]	- noise monitoring - diagnostic (HearTest)	Monthly subscription, cost depends on volume - HearScreen: 6–25 (unlimited) - HearTest: 8–30 (unlimited)	All	Smartphone, headphones	Android
Home Hearing Test[o] [36]	- diagnostic - no screening feature	149	Adults	Laptop/PC, earphones, non-reusable ear tips	Windows
Shoebox[p] [35]	- masking - forehead bone conduction (pro version) - speech discrimination (pro version)	- Standard: 3100 - Professional: 4100	All	tablet	iOS
KUDUwave 5000[q] [37]	- noise monitoring - ambient noise attenuation - diagnostic (Plus, Pro) - masking (Plus) - forehead bone conduction (Plus, Pro) - speech discrimination (Plus, Pro)	- Standard (Prime): 4270 - Plus: 4623 - Pro: 6465	All	Laptop/PC or tablet (additional $1176)	Windows, Android
AMTAS[r] [38]	- masking - diagnostic (Pro) - bone conduction (Pro) - speech discrimination (Pro)	- Flex: NR - Pro: NR	All	Tablet, headphones	
Video-otoscopy	**Key Features**	**Pricing (USD)**	**Interface**	**Additional Required Hardware**	**Compatibility**
Cupris TYM[a]	- Resolution depends on iPhone - video recording - non-adjustable focal length	168.51	External adaptor	Smartphone, proprietary specula	iPhone 5/5s/SE, 6/6s
HearScope[b]	- Resolution: 1920 × 1080 - video recording - manual focus	230	micro USB	Smartphone, proprietary specula	Android
CellScope Oto[c]	- Resolution: depends on iPhone (5s: 1136 × 640) - video recording - tap to focus	299.99	External adaptor	Smartphone, Welch Allyn disposable specula	iPhone 5/5s/SE, 6, 6s, 7
Firefly[d]	- Resolution: 720 × 480 - video recording - manual focus	399.99	USB 1.1/2.0 and above	Laptop/PC, proprietary specula	Windows, Mac
Clearscope[e]	- Resolution depends on smartphone - video recording - manual focus	695.53	Adjustable external adaptor	Smartphone, endoscope, lightsource	Android, iOS
Smart Scope[f]	- Resolution depends on iPhone - video recording - autofocus	701.91	External adaptor	Smartphone, endoscope, lightsource	iPhone 5s/6/6s/7/8, Galaxy S4/5/6/7/8
Dino-Lite Digital Video Otoscope: AM4113-EUT[g]	- Resolution: 1280 × 1024 - video recording - manual focus	699	USB 2.0	Laptop/PC, Welch Allyn specula	Windows, Mac
SyncVision iO1 OTO[h]	- Resolution: 1280 × 720 - video recording - autofocus	995.44	Portable Micro SD card	Laptop/PC	Windows, Mac
Welch Allyn Digital MacroView Video Otoscope[i]	- Resolution: 1280 × 1024 - video recording - manual focus	1079	USB 2.0	Laptop/PC, Welch Allyn power source and specula	Windows

(*continued on next page*)

Table 1 (*continued*)

	Key Features	Pricing (USD)	Intended Age	Additional Required Hardware	Compatibility
endoscope-i[j]	- Resolution depends on iPhone - video recording - non touch focus	1910.09 (phone attachment, endoscope and lightsource)	External adaptor	Smartphone	iPhone 5 and up
MedRx videosccope[k]	- Resolution: 1024 × 768 - video recording - autofocus	NR	USB	Laptop/PC, light source	Windows

NR, not reported; USB, universal serial bus.
[a] Cupris TYM (Cupris Health, Ltd., London, UK).
[b] HearX (HearX Group, Pretoria, South Africa).
[c] CellScope Oto (CellScope, Inc., San Francisco, CA, USA).
[d] Firefly (Firefly Global LLC., Belmont, MA, USA).
[e] Clearscope (Clearwater Clinical Limited, Ottawa, Canada).
[f] Storz Smartscope (Karl Storz, Tuttlingen, Germany).
[g] Dino-Lite AM4113-EUT (Dunwell Tech, Inc., Torrance, CA, USA).
[h] SyncVision iOl OTO (SyncVision Technology Corp., New Taipei City, Taiwan).
[i] Welch Allyn Digital MacroView Video Otoscope (Welch Allyn, Inc., Skaneateles Falls, NY, USA).
[j] endoscope-i (endoscope-i Ltd., Birmingham, West Midlands, UK).
[k] MedRx videosccope (MedRx, Inc., Largo, FL).
[l] AudCal (Jorge Martinez; Apple Inc, Cupertino, CA, USA).
[m] EarTrumpet (Praxis Biosciences).
[n] HearX (HearX Group, Pretoria, South Africa).
[o] Home hearing test (Etymotic Research Inc., Elk Grove Village, Illinois, USA).
[p] ShoeBox (Clearwater Clinical Ltd., Ottawa, Canada).
[q] KUDUwave 5000 (GeoAxon, Pretoria, South Africa).
[r] AMTAS (Grason-Stadler, MN, USA).

is imperative for guiding management and follow-up. Our objective was to evaluate modifications to our prior screening protocol to also include video-otoscopy and a free EMR platform to support more comprehensive, mobile hearing care in a low-resource setting.

2. Methods

2.1. Setting and patients

Our former screening algorithm was piloted in 2016 and 2017 in Port-au-Prince, Haiti and Malindi, Kenya [7–9]. Modifications were tested in Malindi, Kenya in October 2018.

We partnered with a local non-governmental organization, the Caris Foundation, and private and district government hospitals in Malindi, Kenya (Malindi Sub-county Hospital, Tawfiq Hospital) to assemble a team. It consisted of 3 CHWs, an otolaryngology clinical officer (CO) and a nurse. Members were trained by an otolaryngologist in the use of validated, automated audiometry, video-otoscopy (HearX Group, Pretoria, South Africa) and a mobile EMR application (Andaman7, Liege, Belgium) (Fig. 1) [10–13]. Training was conducted in approximately 2 h.

The team traveled to semi-rural schools for screenings. Children ≥5 years were preselected by teachers for screening if there was a concern for potential hearing loss. We previously found teachers can identify at-risk children with 100% sensitivity, allowing more efficient, targeted screening[9].

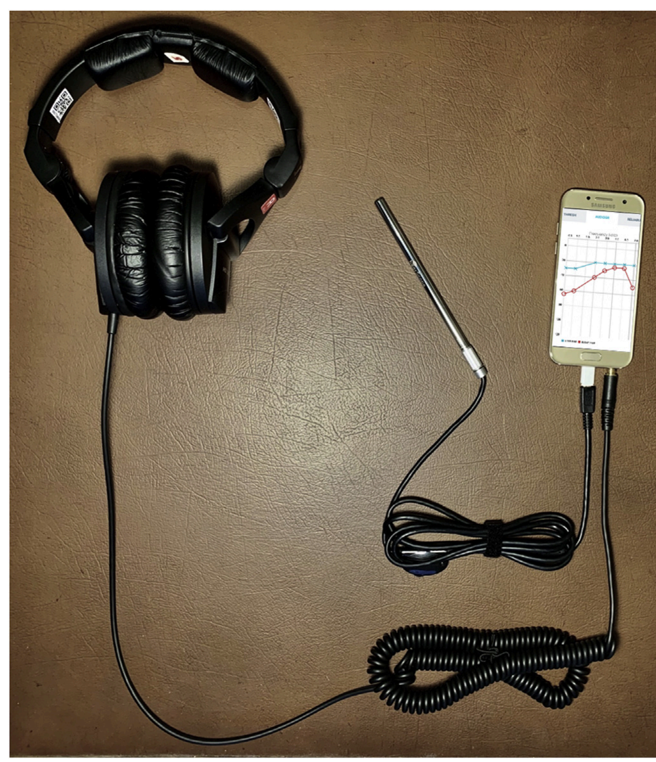

Fig. 1. Smartphone platform with attachment for video-otoscopy. Teams members utilize a cell phone (Samsung A3) to perform hearing screenings and video-otoscopy and create electronic medical records (Andaman7, Belgium). Hearing and video-otoscopy software was developed by HearX (Pretoria, South Africa) and is compatible with calibrated Sennheiser HD280 Pro circum-aural headphones. The accessory camera attachment for video-otoscopy, the HearScope™ (HearX Group) is also shown. For a full list of compatible Android cell phones, please visit the HearX website.

2.2. Protocol

Our protocol is founded on the use of cellular devices to perform portable audiometry and now incorporates video-otoscopy and EMR creation to facilitate point-of-care and remote diagnosis, direct interventions and support follow-up (Fig. 2). Children complete an initial brief hearing screen (HearScreen™), consisting of a pure-tone air conduction screen at 1000 Hz, 2000 Hz and 4000 Hz. The intensity level was set at 25 dB [11–14], well below the level at which intervention has

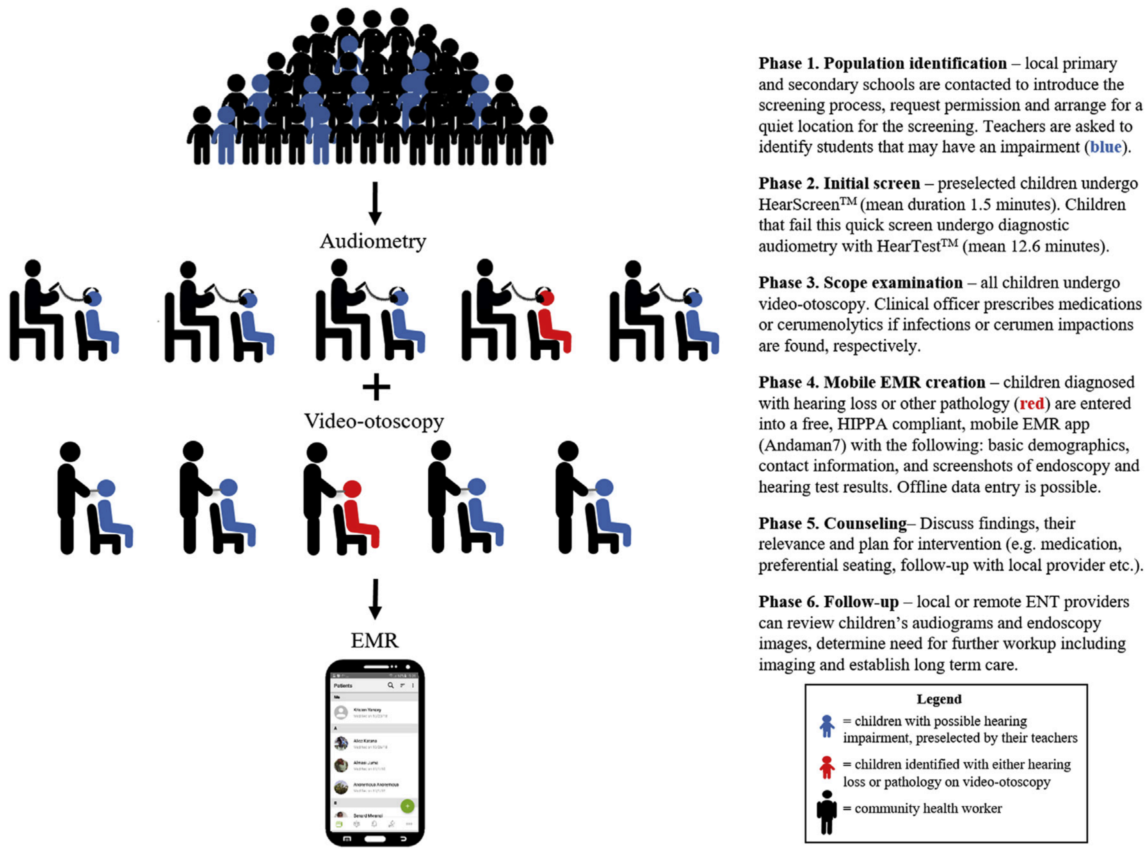

Fig. 2. Updated algorithm that incorporates the use of video-otoscopy and a mobile electronic medical record alongside hearing screening in school-aged children.

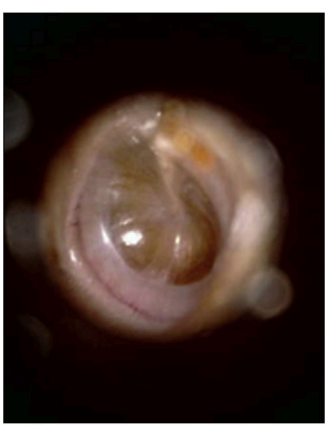

Fig. 3. Image of a left ear taken with video-otoscopy demonstrating an effusion with a centrally retracted ear drum. This child later underwent myringotomy with ear tube placement with removal of copious mucoid material from the middle ear.

been shown to be definitively beneficial at 35 dB [15]. If children failed their initial screen, they undergo a more comprehensive evaluation (HearTest™) for diagnostic audiometry, testing an additional frequency at 500 Hz and at variable intensities from 0 to 90 dB.

All children underwent video-otoscopy (HearScope™). Images were reviewed by an otolaryngologist to verify the diagnosis. Images were also used to familiarize the local CO in recognizing common pathology.

Children with hearing loss or other pathology were entered into a mobile EMR, containing screenshots of their video-otoscopy and hearing results, and referred to the CO's clinic. The EMR is HIPPA compliant, free, user-friendly, capable of offline data-entry, and available in 21 languages. Patient data can be securely shared between providers and parents. Screenings concluded with teacher counseling to discuss findings and recommended interventions.

3. Results

155 children were pre-selected by their teachers and underwent screening (mean age 10.9, range 5–16 years) over four half-day sessions, resulting in 28 (18%) referrals for hearing loss and other pathology. 28 of 28 patients referred (100%) had electronic records successfully created by a CHW. Mean initial screening and diagnostic audiometry duration ± standard deviation was 1.5 ± 1.8 min and 12.6 ± 5.4 min, respectively.

Sixteen (10.3%) failed initial screens and completed diagnostic audiometric evaluations, identifying 10 ears (3.2%) with mild hearing loss, 6 (1.9%) with moderate, 7 (2.2%) with severe, and 5 ears (1.6%) with profound loss. In children with hearing loss, video-otoscopy identified pathology in 13 ears (4.2%), including dry perforations (N = 2), serous effusions (N = 8), OM (N = 4), CSOM (N = 3) and retraction (N = 2).

Pathology was diagnosed in 17 (5.5%) ears (12 children) with normal hearing, including dry perforations (N = 4), serous effusions (N = 9), OM (N = 4), CSOM (N = 1), retraction (N = 6), and fungal otitis externa (N = 2) (Fig. 3).

Overall, the most common pathologies identified were complete cerumen impactions (37 ears, 11.9%), followed by effusions (17 ears, 5.5%), retractions (8 ears, 2.6%), perforations (10 ears, 3.2%) otitis media (8 ears, 2.6%), CSOM (4 ears, 1.3%), and fungal otitis media (2 ears, 0.6%).

4. Discussion

Global pediatric hearing loss is a common, disabling condition disproportionately concentrated in LMICs [2,3,16]. Screening via automated audiometry yields comparable results to standard audiometry and is quicker, cheaper, and more logistically practical for rural settings [17]. To further support hearing care in resource-poor settings, our team has incorporated video-otoscopy and an EMR into a mobile screening protocol that can be administered by individuals without prior medical experience.

4.1. Video-otoscopy complements screening

Pathology was diagnosed in 8.6% of children with normal hearing and in 63% of those with hearing loss. These findings directed the administration of antibiotics, antifungals, and cerumenolytics, in addition to ear cleanings and referrals for local follow-up. A hearing screening protocol that also facilitates the diagnosis and management of infections may offset future hearing disability, as infections are a significant contributor to permanent pediatric hearing loss in LMICs [4,18,19]. However, access to hearing aids and otolaryngologists with the expertise to perform complex surgery is still an area of great need for aural rehabilitation in certain cases.

While tympanometry is standard in traditional audiometry, we believe video-otoscopy to be more practical in LMICs, requiring less equipment and expertise. Data suggests it may be more accurate than tympanometry in diagnosing middle ear pathology [20,21]. Video-otoscopy also facilitates remote consultations, as the consultant is unable to perform an in-person exam.

4.2. Training CHWs

Barriers to hearing initiatives include limited healthcare access with a ratio of 0.01–0.46 otolaryngologists per 100,000 people in sub-Saharan Africa and even fewer Audiologists [22]. CHWs are able to provide a needed service where specialists are scarce [23–25]. We found the integration of hearing screening, diagnostic audiometry, otoscopy and EMR creation was feasible for a team with highly variable medical experience. The team was facile at implementing the algorithm with under 2 h of training. The addition of EMR did not compromise the overall efficiency of screening, as charts were created only for the children found to have hearing loss and/or pathology. In this series, CHWs successfully created charts for 28 children out of 155 screened.

4.3. Benefits of school-based screenings

Our experience over the past 3 years in Kenya and Haiti suggest in-school screenings are beneficial in several ways. Pediatric hearing loss is most often secondary to acquired etiologies and unlikely to be detected on newborn hearing screening, presenting more often in school-aged children [3,26]. In LMICs, children are more likely to attend schools regularly than to be established with a pediatrician. Second, it removes the transportation burden from caregivers. Third, it empowers teachers in the hearing loss effort. They may be the first to suspect an impairment and can preselect for hearing loss screening with high sensitivity [9]. Furthermore, teachers are poised to implement preferential seating, moderate environmental noise exposure, and identify those in need of speech and language therapy. Moreover, their involvement in hearing initiatives may increase awareness that academic underperformance may reflect a hearing impairment and not aptitude.

4.4. Follow-up is instrumental to sustainability

Follow-up has been a barrier to our prior protocol iterations and other screening initiatives [27,28], prompting the inclusion of a mobile EMR to track outcomes. EMR also allows for remote consultation. Telemedicine is a burgeoning field working to extend access to healthcare resources [29] including cochlear implant programming, and speech therapy [27].

Thoughtful engagement of teachers also promotes continuity of care as they play a pivotal role in conveying findings and recommendations to parents. Lack of knowledge regarding ear infections and screening results are common reasons cited for loss of follow-up [30,31]. It is helpful to review a “Summary” report with teachers of the children identified with hearing loss or other pathology and the recommended interventions and follow-up.

4.5. Limitations and future directions

The authors acknowledge there are limitations to the current study including the absence of masking, formal tympanometry, limited follow-up and presence of ambient noise. As screenings were conducted in schools, the studied population was restricted to older students and did not capture children that had not yet begun primary schooling. Furthermore, we also found children under five years of age tended to fatigue with during the diagnostic audiometry, yielding unreliable responses. Subsequently, no children under 5 years old were included in the final analysis. Further work is necessary to incorporate efficient screening of children younger than 5 into the current protocol. Obtaining serial audiometry on previously tested at-risk children is of great interest and will be a priority during the next surgical mission trip to the area.

Future directions include expanding screening to include Distortion Provoked Otoacoustic Emissions (DPOAE), Audiometric Brainstem Response (ABR) testing, and assessing tympanic membrane compliance using a smartphone platform [32]. Other improvements to the current protocol are anticipated as masking for air conduction and bone conduction software are under development. Additionally, the incorporation of a deep-learning algorithm supporting real-time, automated diagnosis of pathology from video-otoscope images is in progress.

5. Conclusion

Early identification and intervention are key tenets in the prevention of pediatric hearing loss and its associated morbidities to reduce the individual, societal and overall global burden of disease. Our updated protocol diagnoses existing hearing loss and conditions that predispose to future impairment. It is the only unified, portable platform that incorporates hearing screening, diagnostic audiometry and video-otoscopy, obviating the labor intensive task of transferring data between devices. Its other strengths include its ease-of-use, relative cost-effectiveness, integral involvement of CHWs, support for follow-up, and ability for remote consultation.

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Conflict(s) of interest to declare

None.

Institutional review board approval

Vanderbilt University IRB exempt.

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