**Hearing Impairment in Children Living with HIV in Haiti**

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**Abstract**

**Objective**: To identify the prevalence of hearing impairment and associated risk factors in children living with human immunodeficiency virus (HIV) in Haiti.

**Methods**: A validated smartphone-based platform with pure-tone audiometry was used to screen 341 HIV-infected children for hearing impairment in Port-au-Prince, Haiti from March 2019 to September 2020. If screening was failed, a more comprehensive pure-tone audiometric evaluation was administered. Demographic, otologic, and HIV-related data were obtained through caregiver surveys and medical charts. Statistical analysis included univariate and multivariate logistic regression.

**Results**: Sixty (18%) of 341 HIV-infected children (ages 7–18 years) had hearing impairment. Of those failing their hearing assessment, 17 (28%) had moderate and 5 (8%) had severe or profound hearing loss. Hearing impairment was associated with frequent ear infections (OR 3.37; 95% CI 1.76–6.46; p<0.001) and family history of hearing loss (OR 5.12; 95% CI 2.14–12.23; p=0.001) but not viral load (OR 1.00; 95% CI 0.73–1.02; p=0.28) or antiretroviral therapy duration (OR 0.96; 95% CI 0.79–1.17; p=0.66). Only 35% of caregivers correctly perceived their child’s hearing loss.

**Conclusions**: Hearing impairment occurs at a higher prevalence in HIV-infected children in Haiti than what is expected for those living without HIV. Frequent ear infections were significantly associated with hearing loss while antiretroviral therapy duration was not. Despite their potential ototoxicity, antiretroviral therapies should be continued and may decrease incidence of otitis media. Low caregiver perception of hearing loss emphasizes the need for routine hearing screening for HIV-infected children.

**Key words**: HIV, hearing loss, hearing screening, Haiti, children, public health

**1. Introduction**

 The World Health Organization (WHO) estimates that 432 million adults and 34 million children globally have disabling hearing loss, the most common congenital sensory impairment, and that nearly 60% of these cases are preventable [1]. Unaddressed hearing impairment can have devastating consequences on speech and language development and future educational and employment opportunities [2]. However, hearing-related disability and associated costs can be largely curtailed with timely diagnosis of hearing impairment and appropriate interventions [3].

 A majority of children suffering from hearing impairment are from low- and middle-income countries, which also bear the overwhelming burden of the human immunodeficiency virus (HIV) [1, 4]. Studies thus far have mainly used small sample sizes to report variable prevalence of hearing impairment among HIV-infected children, ranging from 6.4% to 84.8% [5-13]. These rates are higher than those in uninfected children: 38.8% versus 6.9% in Peru [11, 14], 21.6% versus 8.3% in South Africa [10], and 20% versus 10.5% in the United States [5]. Etiologies of hearing impairment in HIV-infected individuals have been attributed to recurrent otitis media; opportunistic infections like cytomegalovirus (CMV) and tuberculosis (TB); and ototoxic side effects from medications including streptomycin, gentamicin, and nucleoside reverse transcriptase inhibitors [15-18].

Specifically in Haiti, the Caribbean country with the highest number of individuals living with HIV, prevalence of hearing impairment has not been reported in the HIV population, let alone in children infected with the virus. In recent years, Haiti has achieved considerable success with HIV treatment due to sexual behavior changes and care delivery improvements in both rural and urban areas [19]. However, with an increasing number of individuals living with HIV, morbidity such as hearing impairment, rather than mortality, has risen on the public health agenda. Adequate attention to hearing health, especially for vulnerable populations like children, can be extremely difficult when widespread unemployment, inadequate shelter, and food scarcity affect the country [19, 20]. This study was thus developed to i) characterize the prevalence of hearing impairment among HIV-infected children in Port-au-Prince, Haiti and ii) identify associated risk factors of hearing loss. Together, these findings can help inform strategies for timely identification and treatment which can minimize developmental delays and hearing-related disability.

**2. Methods**

This cross-sectional study involved HIV-infected children between ages 7 and 18 years who were recruited from five hospitals in Port-au-Prince, Haiti between March 2019 and September 2020. These hospitals were affiliated with Caris Foundation, an international nonprofit organization that offers a club-based health education program for children and women living with HIV [21]. Primary caregivers were invited to enroll their children in hearing screening when they presented for their monthly club meetings. Travel reimbursement was provided for the club meeting; participants did not receive compensation specifically for this study. The only exclusion criterion was inability or refusal of the child to participate. Informed consent was attained from each guardian and participant older than 17 years, and each child’s verbal assent was confirmed prior to proceeding. Consents, instructions, and screening were completed in Haitian Creole, the local language of participants and their caregivers. Human subject approvals were obtained from the Vanderbilt University Medical Center (#170620) and National Haitian Institutional Review Board (#1718-67). Caris Foundation and their affiliated five hospitals also formally agreed to this study.

*2.1 Hearing Screening Protocol*

Employing validated, smartphone-based audiometry (HearX Group, Pretoria, South Africa), our screening algorithm has been previously described in Haiti and Kenya [22-27]. Initial testing (HearScreenTM) involved pure-tone air conduction screen at 1000 Hz, 2000 Hz, and 4000 Hz. All screenings were performed in a relatively quiet room. Based on representative noise measurements at the sites, intensity was set at 30 dB HL to account for any ambient noise. Despite the decreased screening sensitivity, these measurements were still below the level at which the Global Burden of Disease Expert Group on Hearing Loss recommended that intervention would yield definitive benefits (35 dB HL) [28]. If the child failed initial screening, comprehensive pure-tone audiometry was then administered at frequencies of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz and at intensities ranging from 0 to 90 dB HL. “Pass” was noted if pure-tone thresholds were < 30 dB HL. Otherwise, the degree of hearing impairment in each ear was categorized according to the WHO parameters: mild (31-40 dB HL), moderate (41-60 dB HL), severe (61-80 dB HL), and profound (>81 dB HL) [29]. Patients with hearing impairment were referred for further evaluation and treatment by an audiologist and otolaryngologist. In addition, the research team helped coordinate surgical trips by otologists from the United States who helped train Haitian otolaryngologists in various otologic repair techniques (e.g. tympanoplasty, tympanomastoidectomy) using local equipment and resources when indicated.

*2.2 Chart Review and Questionnaires*

 Patient medical records were reviewed to identify demographic variables such as age and gender, highly active antiretroviral therapy (HAART) and duration, and HIV viral load. Viral load was typically recorded at the same visit in which the audiometric evaluation was taken. In instances in which an audiometric evaluation occurred when no blood draw occurred, the most recent viral load data was extracted from the chart. A brief 7-item questionnaire (**Appendix**) was also completed by caregivers to attain further data on hearing history. These questions targeted whether the child had frequent ear infections, otalgia, otorrhea, and previous ear surgery as well as any hearing aid use and family history of hearing loss.

*2.3 Statistical Analysis*

 Means and standard deviations were used to summarize continuous variables, and frequency counts and percentages were used to describe categorical variables. The Student *t-*test and chi-square test were performed for correlations between continuous and categorical variables, respectively. Univariate and multivariate regression analyses were used to determine the effects of demographic, otologic, and HIV-related characteristics on hearing impairment. Data were analyzed using SPSS software, version 21.0 (IBM Corp., Armonk, NY), and *p* values less than 0.05 were considered statistically significant.

**3. Results**

 Of the 345 children who were offered hearing screening, one caregiver declined enrollment; two patients were excluded due to cognitive impairment and active tuberculosis; and one patient was lost to follow-up after failing initial testing (**Figure 1**). Sixty (18%) of 341 HIV-infected children ultimately failed hearing screening. Over one-third of patients had at least moderate hearing loss in one ear, and 33 (55%) had bilateral hearing impairment. Audiometry results are presented in **Table 1**.

The mean age for this cohort was 12.7 years (range 7–18), and 185 (54%) were female. Hearing impairment was significantly associated with increased frequency of ear infections (32% vs 12%, p<0.001); otorrhea (25% vs 11%, p=0.003); otalgia (32% vs 17%, p=0.01); and family history of hearing loss (18% vs 4%, p<0.001). Among the group with hearing impairment, only 21 (35%) caregivers correctly perceived their child’s hearing loss. Five children had hearing aids, and three children reported prior ear surgery. Demographic and otologic data are summarized in **Table 2**.

*3.1 Association with HIV and HAART*

 HIV-related data were incomplete for many patients due to partial documentation, guardianship changes, and hospital transfers since enrollment. Viral load was available for 73 patients, and prevalence of hearing impairment was similar between those who were virally suppressed (i.e. less than 400 copies/ml) and those who were not (26% vs 25%, p=0.674). Of the patients whose HAART duration was available (n=82), 21 (26%) were diagnosed with hearing impairment. There were no significant differences in duration of HAART between children who failed screening (5.28 years + 3.1) and those who passed (4.96 years + 2.5) (p=0.703).

*3.2 Risk Factors for Hearing Impairment*

 Logistic regression suggests that frequent ear infections (OR 3.37, 95% CI 1.76—6.46; p<0.001) and family history of hearing loss (OR 5.12, 95% CI 2.14—12.23; p=0.001) were associated with hearing impairment on univariate analysis (**Table 3**). Multivariate logistic regression modeling included age, gender, frequent ear infections, family history of hearing loss, viral load, and HAART duration. In this model, only history of frequent ear infections (OR 3.90, 95% CI 1.02—14.85; p=0.046) was significant.

**4. Discussion**

*4.1 Prevalence of Hearing Impairment*

 To our knowledge, this is the first study to report on hearing impairment and associated risk factors in HIV-infected Haitian children. In this cohort of 341 children, the prevalence of hearing impairment was 18% which is substantially greater than the WHO estimate of 1.6% for childhood hearing loss in the Caribbean and Latin America [30]. Most literature on hearing impairment in HIV-infected children focuses on Africa where HIV is more endemic [6, 8-10]. Among those studies conducted in Latin America, hearing impairment’s prevalence was 33% in Mexico (n=12), 38.8% in Peru (n=139), and 84.8% in Brazil (n=23) [7, 11, 12]. These higher rates can be explained by notably smaller cohorts as well as lower thresholds for diagnosing hearing loss, ranging from 15 to 25 dB HL versus 30 dB HL that was used in this study. Furthermore, advanced stages of HIV are significantly associated with higher rates of hearing loss [5, 8]. Compared to cohorts in the other Latin American studies, the children in this study, who are beneficiaries of the Caris Foundation, are more likely to have regular follow-up and treatment adherence. This helps further account for this cohort’s relatively lower prevalence rate for hearing impairment.

 In addition to being the first report in Haiti, this study also has the largest cohort to date of hearing impairment in HIV-infected children in the Caribbean and Latin America. After sub-Saharan Africa, the Caribbean has the second highest HIV infection rate, and Haiti represents 47% of all Caribbean people living with HIV [19, 31]. As such, identifying hearing impairment rates in Haiti and the Caribbean is an important step in the global fight against HIV and its related morbidities. Children are especially susceptible to speech and developmental delays secondary to hearing impairment [2]. In Haiti, HIV-infected individuals’ children are already known to face disadvantages in basic needs such as housing and food as well as school enrollment and performance [19]. By focusing on characterizing prevalence and risk factors of hearing impairment among HIV-infected Haitian children, this study fulfills a key gap in the literature and can inform strategies for addressing hearing health in this vulnerable population. Our team has further expanded the screenings beyond HIV-infected children to include healthy children through a school-based hearing screening program in Haiti.

*4.2 Risk Factors for Hearing Impairment*

 Compared with those who did not have hearing loss in this study, hearing impaired HIV-infected children had a significantly higher prevalence of frequent ear infections (32% vs. 12%) and likely associated otorrhea (25% vs. 11%) and otalgia (32% vs. 17%). Frequent ear infections were a risk factor for hearing impairment in both univariate and multivariate analyses. Several studies support this association of acquired middle ear disease with hearing loss [8, 9, 11, 32]. To help explain these findings, effusions and tympanic membrane perforations from otitis media can generate conductive hearing loss, the most common hearing loss type that is observed in HIV-infected children [11, 33].

 With respect to other risk factors evaluated in this cohort, univariate and multivariate analyses did not detect significant correlations between viral load or HAART duration and hearing impairment. Previous studies have primarily focused on CD4 cell counts which are not available in Haiti as national guidelines in 2016 recommended shifting toward regular monitoring of viral load rather than CD4 cell counts [34]. A low CD4 cell count, a marker for weaker immune status, has been significantly associated with hearing impairment and tympanic membrane perforations [11, 35, 36]. On the other hand, viral load has conflicting results, partly due to inconsistent cutoffs of copies per ml to determine levels of viral suppression. For example, Buriti et al. found a direct correlation between hearing loss and viral load in Brazil [7], and Chao et al. actually noted an inverse relationship in Peru [11]. Our study is consistent with most recent reports, which revealed no significant association between viral load and hearing impairment in Mexico, Malawi, and South Africa [7, 8, 10, 12].

Moreover, the lack of correlation between HAART and hearing impairment has been well-documented in the literature [8, 9, 11, 13]. While some studies demonstrate that longer duration on HAART is associated with hearing impairment, there was no significant correlation found in our cohort [9, 11]. Longer HAART duration may serve as a marker for later stages of HIV which have been associated with higher risks for hearing impairment and otitis media [5, 8, 13]. At the same time, our findings suggest that adherence to HAART is likely beneficial for hearing health despite concerns for ototoxicity [15-18]. The low prevalence of sensorineural and mixed hearing loss in HIV-infected children further suggests that hearing impairment is not primarily due to ototoxicity from HAART [8, 11, 37]. Altogether, these results strongly support continued HAART treatment for HIV-infected children; despite its potential ototoxicity, HAART remains advantageous for not only HIV treatment but also hearing health in this population.

*4.3 Low Caregiver Perception of Hearing Impairment*

Paralleling findings in Malawi, caregivers in this study were unreliable in perceiving their child’s hearing impairment [8]. Only 35% of caregivers with hearing impaired children correctly predicted their child’s hearing loss. Of those children with normal hearing, 14% of caregivers reported that their child had difficulties with hearing. To explain these results, the threshold of 30 dB HL that was used to cancel ambient noise and diagnose hearing loss in this study could have resulted in the lack of diagnosis in one ear. In addition, the high prevalence of cognitive delays and central auditory processing disorders in HIV-infected children can make these conditions difficult to distinguish from hearing impairment for caregivers [38, 39]. Ultimately, the inadequacy of caregiver perception highlights the importance of hearing screening protocols for HIV-infected children. Prompt diagnosis and treatment of otitis media, a significant risk factor for hearing impairment in this population, deserve special attention in future public health interventions.

*4.4 App-based Hearing Screening in a Low-Resource Setting*

 The ability to gather basic otologic data on a cellphone-based application in a low-resource setting such as Haiti, where sound booth audiometry is rare, enhances the ability to fulfill basic hearing screening needs in low- and middle-income countries [40]. These areas also have the highest prevalence of disabling hearing loss, further increasing the need for novel diagnostic modalities using technology in order to expand care delivery [2]. Moreover, app-based hearing screenings can improve audiometric evaluation in remote settings even in high-resourced countries (e.g. Alaska) [41]. This study thus showcases that basic hearing screening data can successfully be attained in low-resource settings using an application platform.

*4.5 Strengths and Limitations*

 The strengths of this study include a large cohort, validated hearing assessment, and a broad range of data that was collected from medical records as well as caregiver surveys. Limitations include recall bias from those surveyed, lack of an HIV-uninfected control group, and incomplete data related to viral load, HAART, and opportunistic infections (e.g. CMV, TB). Furthermore, comprehensive otolaryngologic evaluation and confirmatory audiometric testing, although offered to families, were outside the scope of this study. As such, specific diagnostic causes of hearing loss were not reported here. Civil unrest in Haiti also led to inconsistent availability of skilled professionals who could conduct otoscopic examinations at the time of screening and, therefore, were not completed. Future studies for characterizing hearing impairment in Haiti and the Caribbean can focus on differentiating the type of hearing loss (i.e. sensorineural, conductive, mixed), with the use of an HIV-uninfected control group and more comprehensive medical data.

**5. Conclusions**

Hearing impairment in HIV-infected Haitian children was 18% which is substantially higher than the WHO estimate of 1.6% for childhood hearing loss in the Caribbean and Latin America. Frequent ear infections significantly increased the risk of hearing loss while HAART duration and viral load did not. Despite their potential ototoxicity, HAART should be continued and may decrease the incidence of otitis media. Given low caregiver perception of hearing impairment, routine screening protocols need to be implemented for HIV-infected children. In areas with political instability and low access to otolaryngologists and audiologists, sustainable mobile screening tools such as HearScreenTM can be integrated into these protocols.

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Figure 1. Flow chart for screening and diagnosis of hearing loss in HIV-infected children.

Table 1. Hearing Impairment Results (N = 60).

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Unilateral (%)** |  | **Bilateral (%)** |
| >30 dB HL pure tone average | 27 (45) |  | 33 (55) |
| Mild | 20 (33) |  | 18 (30) |
| Moderate | 7 (12) |  | 2 (3)  |
| Moderate in one, mild in other | - |  | 8 (13) |
| Severe in one, moderate in other | - |  | 1 (2) |
| Profound | - |  | 4 (7) |

Table 2. Participant Characteristics and Otologic History.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Hearing Impairment** |  | **Normal Hearing** |  |
|  | n (%) |  | n (%) |  *P* value |
| All | 60 (100) |  | 281 (100) |  |
| Age (years)A | 12.7 + 2.3 |  | 12.7 + 2.6 | 0.955 |
| Female gender | 34 (57) |  | 151 (54) | 0.776 |
| Perception of HI by caregiver | 21 (35) |  | 40 (14)  | **<0.001** |
| History of frequent ear infections | 19 (32) |  | 34 (12) | **<0.001** |
| Otorrhea | 15 (25) |  | 30 (11) | **0.003** |
| Otalgia | 19 (32) |  | 48 (17) | **0.010** |
| Family history of HI | 11 (18) |  | 12 (4) | **<0.001** |

Significant *p* values in bold.

ADisplayed in mean + standard deviation.

HI indicates hearing impairment.

Table 3. Independent Predictors of Hearing Impairment.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Unadjusted** |  | **Adjusted**A |
|  | OR (95% CI) | *P* value | OR (95% CI) | *P* value |
| Age (years) | 1.00 (0.90 – 1.12) | 0.96 |  | 1.05 (0.82 – 1.35) | 0.68 |
| Gender | 1.12 (0.64 – 1.96) | 0.68 |  | 2.29 (0.67 – 7.89) | 0.19 |
| Frequent ear infections | 3.37 (1.76 – 6.46) | **<0.001** |  | 3.90 (1.02 – 14.85) | **0.046** |
| Family history of HI | 5.12 (2.14 – 12.23) | **0.001** |  | 2.59 (0.59 – 11.21) | 0.20 |
| Viral load | 1.00 (0.73 – 1.02) | 0.28 |  | 0.98 (0.64 – 1.25) | 0.28 |
| Duration of HAART  | 0.96 (0.79 – 1.17) | 0.66 |  | 1.05 (0.83– 1.32) | 0.70 |

Significant *p* values in bold.

AAdjusted for other variables in table.

HAART indicates highly active antiretroviral therapy; HI indicates hearing impairment.

Appendix. Hearing Screening Questionnaire.

1. Do you feel that your child’s hearing is impaired?
2. Has your child had many ear infections?
	1. Yes
		1. If so, how many in the past year?
	2. No
3. Has your child had foul-smelling fluid draining from the ears?
	1. Yes
	2. No
4. Has your child said that his/her ears hurt?
	1. Yes
	2. No
5. Has your child ever had a hearing aid?
	1. Yes
	2. No
6. Has your child ever had ear surgery?
	1. Yes
	2. No
7. Does anyone in your child’s family have problems with hearing loss?
	1. Yes
	2. No