The Laryngoscope

Tele-otology for Aboriginal and Torres Strait Islander People Living in Rural and Remote Areas

Al-Rahim Habib, MD, MSc; Graeme Crossland, MBChB, DOHNS, MD, FRCS, FRACS; Raymond Sacks, MBBCH, FCS, (SA)ORL, FRACS, MMed; Narinder Singh, MBBS, MS, FRACS; Hemi Patel, BSc, MSc, DLO, FRCS, FRACS

Objective: To evaluate a referral-based, tele-otology service in rural and remote areas of the Northern Territory, Australia.

Methods: A retrospective observational cohort study was performed of a tele-otology service in 93 Aboriginal and Torres Strait Islander communities (2011 to 2019). Assessments included face-to-face examinations performed by Clinical Nurse Consultants and audiologists, and asynchronous reviews performed by otolaryngologists. Multivariable logistic regression was performed to determine the likelihood of ear disease, adjusted for age and gender. Intra- and inter-rater agreement was assessed between otolaryngologists.

Results: A total of 3,950 patients were reviewed (6,838 encounters, 13,726 ear assessments). The median age of patients was 9.8 years (interquartile range: 7.2 years). Overall, 62.2% of patients were identified with ear disease and 62.5% identified with hearing loss. Substantial intra- and inter-rater agreement in diagnosis was found between otolaryngologists ($\kappa = 0.71$ and $\kappa = 0.78$, respectively). The most common ear conditions identified were chronic otitis media (COM, 28.1%) and otitis media with effusion (OME, 16.5%). Topical or oral antibiotics were initiated in 14.1% of all encounters, most often for acute otitis media or COM. Surgery was recommended in 27.7% of all encounters, most often myringoplasty, adenoidectomy, and myringotomy with insertion of tympanostomy tubes.

Conclusion: Tele-otology is a critical component of an integrated approach to evaluating ear disease in Indigenous people living in rural and remote areas. The high prevalence of OME, COM, and surgical recommendations highlights the need for community engagement, regular follow-up, and early interventions to prevent long-term hearing loss.

Key Words: epidemiology, otitis media, otology, telehealth.

Level of Evidence: NA

***Laryngoscope*, 134:5096–5102, 2024**

INTRODUCTION

Aboriginal and Torres Strait Islander people living in rural and remote areas of Australia experience a high burden of ear disease.[1–3] Recurrent otitis media can be associated with long-term hearing loss and can contribute to detrimental lifelong impacts on speech and language development, academic performance, behavior, social isolation, future employment opportunities, and increased contact with the criminal justice system.[4–7] The prevalence of self-reported ear or hearing problems are greatest in the Northern Territory (NT) where geographical, cultural, and logistical factors can impact the delivery of hearing health services.[8]

Telehealth services have been developed to overcome geographical barriers to specialist access, reduce costs associated with travel, and partner with community organizations to establish culturally appropriate and sustainable care.[9,10] Real-time consultations can be conducted between the patient, family, regional clinician (referrer), and offsite otolaryngologists.[11] In rural settings, real-time videoconferencing telehealth assessments demonstrate high concordance with face-to-face assessments to establish diagnoses and surgical management decisions.[9] However, the real-time model of care relies on suitable resources, including videoconferencing equipment and

From the Sydney Medical School, Faculty of Medicine and Health (A.-R.H., R.S., N.S.), University of Sydney, Sydney, New South Wales, Australia; Department of Otolaryngology—Head and Neck Surgery (A.-R.H., G.C., H.P.), Royal Darwin Hospital, Top End Health Service, Department of Health, Tiwi, Northern Territory, Australia; and the Department of Otolaryngology—Head and Neck Surgery (A.-R.H., N.S.), Westmead Hospital, Sydney, New South Wales, Australia.

Additional supporting information may be found in the online version of this article.

Editor's Note: This Manuscript was accepted for publication on June 17, 2024.

Research Scholarship from the Garnett Passe and Rodney Williams Memorial Foundation (Dr Al-Rahm Habib). Microsoft AI for Humanitarian Action Grant (Dr Al-Rahim Habib). Avant Foundation Doctor-in-Training Research Grant (Dr Al-Rahim Habib).

ARH discloses research funding from the Garnett Passe and Rodney Williams Memorial Foundation, Microsoft AI for Humanitarian Action grant, and the Avant Foundation Doctor-in-Training research grant. RS is a consultant for Medtronic. NS discloses research funding from Microsoft's AI for Humanitarian Action grant, consultant for ResMed, Optinose, Nasus, GSK, and ENT Technologies, and has received conference funding from Medtronic, Karl Storz, and NeilMed. GC and HP have no disclosures or conflicts of interest to report.

Send correspondence to Al-Rahim Habib, Sydney Medical School, Faculty of Medicine and Health, University of Sydney, Sydney, NSW, Australia. Email: al-rahim.habib@sydney.edu.au

DOI: 10.1002/lary.31624

facilities on-site, trained personnel on-site, and access to reliable Internet service with adequate bandwidth for transmission of live video feeds.[12]

Alternative strategies such as asynchronous, "store-and-forward" telehealth approaches have been utilized.[13] One approach for community-based mobile screening services utilizes a dedicated vehicle equipped with video otoscopes, audiometric testing equipment, and an Aboriginal health worker with advanced hearing-health training.[10] The vehicle includes a wireless broadband connection for transmission of data but uses asynchronous data transfer rather than live video feeds. This approach has contributed to an increase in referrals to otolaryngologists and reduced waiting time for specialist review.[14] Such asynchronous, "store-and-forward" telehealth strategies, known as "tele-otology" are valuable because specialists can review data when convenient, utilize data managers to organize examination results into truncated packages for expedited review, and can tailor participation relative to competing clinical commitments. In addition, complex equipment, remote transmission facilities, and trained personnel can remain with the dedicated vehicle, rather than requiring duplication of equipment and staff at multiple remote locations.

A "store and forward" tele-otology model has been used in rural and remote Indigenous communities in the NT, following its inception by authors HP and GC. Patients identified in primary care with persistent middle ear disease are referred to the NT Ear, Nose and Throat (ENT) service for tele-otology or specialist outreach assessment. The tele-otology service is comprised of a specialty-trained Clinical Nurse Consultant (CNC) and an audiologist who can perform detailed face-to-face ear assessments to all major communities and homelands in the NT. The tele-otology team are equipped with mobile computer workstations to perform ear examinations (i.e., digital video otoscopy, tympanometry, audiometry). Clinical information is collected during community visits and subsequently reviewed by metropolitan otolaryngologists. This model of care provides a broad range of ear health services to individuals from rural and remote communities, and has established standardized, high-quality ear examination data for otolaryngologist review.

The aim of this study was to review the referral-based, tele-otology ear health service in the NT since its inception in 2011, and to summarize the identified burden of ear disease in Aboriginal and Torres Strait Islander people from these rural and remote areas.

METHODS

Ethics approval was obtained from the Menzies School of Health Research, Northern Territory, Australia, (HREC: 2019-3410). This research was conducted in accordance with the Helsinki Declaration and with the support and approval of the Aboriginal communities involved.[15]

The tele-otology ear health program, initiated by the Department of Otolaryngology at the Royal Darwin Hospital (Darwin, Northern Territory, Australia), was conducted in collaboration with the Northern Territory Outreach Hearing Health Program. Digital ear exams and specialist assessments were prospectively collected from March 7, 2011 to May 2, 2019, and retrospectively reviewed. CNCs with otology training and audiologists performed ear examinations, which included history-taking, digital video otoscopy, audiometry, and tympanometry. Examination data were documented on a standardized proforma (Figure S1) and stored electronically for review.

Otolaryngologists at the Royal Darwin Hospital reviewed the examination data (Figure S2), along with previous tele-otology assessments, audiograms, and operation reports, to establish diagnoses, management recommendations, and follow-up plans. Diagnostic categories included: normal (no abnormality detected), acute otitis media (AOM) with or without perforation, otitis media with effusion (OME), chronic otitis media with actively discharging perforation (COMwAP), chronic otitis media with inactive dry perforation (COMwDP), healed perforation, cholesteatoma, Eustachian Tube Dysfunction (ETD), otitis externa (OE), foreign body or wax obstruction, presence of tympanostomy tube (in situ, blocked, discharging, extruded), and postoperative evaluations.

Management recommendations included: medical treatments (topical or oral antibiotics), aural toilet, foreign body removal, and surgical recommendations (examination under anesthesia, myringotomy with insertion of tympanostomy tubes, myringotomy with insertion of tympanostomy tubes and adenoidectomy, exploration of middle ear or mastoid, myringoplasty).

Patients were screened by local primary health care service practitioners and referred to the mobile tele-otology service for further assessment. Patients subsequently requiring face-to-face otolaryngologist review or surgical intervention were evaluated at the Royal Darwin Hospital, NT, Australia.

Statistical Analysis

Demographic characteristics (age, gender) were summarized using descriptive statistics including mean, interquartile range, absolute frequency, or relative proportions. Hearing loss (HL) was classified by type (conductive, sensorineural, mixed, none, incomplete assessment) and degree (mild [16–30 dB HL in soundproof conditions; 26–35 dB HL in non-soundproof conditions], moderate [31–60 dB HL in soundproof conditions; 36–60 dB HL in non-soundproof conditions], severe [61–90 dB HL in soundproof conditions or non-soundproof conditions], profound [91+ dB HL either in soundproof conditions or non-soundproof conditions], indeterminate).[16]

Associations between variables were assessed using odds ratios (OR) with 95% confidence intervals (95% CI) and the chi-squared test. Logistic regression determined the association between ear disease and age, gender, and assessment year. A secondary analysis included participants with two tele-otology reviews, comparing ear disease and hearing loss prevalence between the first and second assessments.

Fifty randomly selected patients with prior tele-otology assessments were included for intra- and inter-rater agreement evaluation. Fellowship-trained otolaryngologists (HP and GC) with extensive Indigenous outreach experience in NT, Australia, evaluated de-identified, coded, and randomized assessments. Two sessions (Attempt 1 and Attempt 2) with an interval of at least 1 week were conducted. Raters were presented with eight diagnostic options (e.g., no middle ear disease, AOM without perforation, etc.). Inter-rater agreement was assessed using Cohen kappa statistics (κ) with standard interpretations (<0.21 slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, >0.80 near complete agreement).[17]

RESULTS

Demographics

A total of 3950 individuals were reviewed from 93 communities within the observation period, consisting of 13726 tele-otology ear assessments. Of all the assessments, 12385 (89.8%) included sufficient clinical information, image quality, and patency of the external acoustic canal for the otolaryngologist to establish a diagnosis and management plan. Assessments were excluded due to obstruction of the external acoustic canal from wax or foreign bodies ($n = 186$, 1.4%) and incomplete assessments without corresponding otoscopic images, audiometry, or clinical history ($n = 1155$, 8.4%). Throughout the observation period, 2354 (59.6%) individuals received one assessment, 854 (21.6%) individuals received two assessments, and 742 (18.8%) individuals received three or more assessments.

Table I provides the age distribution of the patients reviewed by the tele-otology service. Most individuals were between 7 to 16 years of age (56%) with a similar distribution of females and males. On average, 759 individuals (interquartile range: 402 individuals) were evaluated each year in the tele-otology service.

Rater Agreement

Substantial intra- and inter-rater agreement for ear disease diagnoses was found (overall intra-rater agreement $\kappa = 0.71$; inter-rater agreement $\kappa = 0.78$, Table II). Raters achieved complete agreement to classify AOM with perforation, COMwAP, and COMwDP ($\kappa = 1.00$). Raters achieved near complete agreement to classify normal aerated ears ($\kappa = 0.88$), substantial agreement to classify OME ($\kappa = 0.82$), and moderate agreement to classify ETD ($\kappa = 0.64$) and AOM ($\kappa = 0.56$).

Prevalence of Ear Disease and Hearing Loss

During the observation period in the tele-otology program, the proportion of individuals with ear disease was 62.2%, consisting of 34.1% with bilateral ear disease and 28.1% with unilateral ear disease. The proportion of individuals with hearing loss was 62.5%, consisting of 37.3% with bilateral hearing loss and 25.2% with unilateral hearing loss. Since inception of the tele-otology program, assessments related to postoperative reviews, ETD, AOM with perforation, and COMwDP increased with each year of the service (Fig. 1).

Ear assessments were comprised of 4442 (35.9%) normal aerated ears, 7542 (60.9%) with ear disease, 300 (2.4%) postoperative reviews, and 101 (0.8%) tympanostomy tube reviews. Of cases with ear disease, the most common middle ear conditions identified were OME (16.5%), COMwAP (14.1%), and COMwDP (14.0%) (Table III).

Hearing loss was comprised of conductive (59.8%), indeterminate (34.7%), sensorineural (2.8%), and mixed (2.7%) hearing loss.

TABLE I.
Summary of Demographic Characteristics for Tele-otology Assessments Completed at the Royal Darwin Hospital, Northern Territory, Australia From 2011 to 2019.

	Total Cohort ($n = 3950$)	
	n	%
Age		
≤3 years	419	10.6
4 to 6 years	564	14.3
7 to 16 years	2227	56.4
≥17 years	740	18.7
Gender		
Female	2016	51.0
Male	1934	49.0

TABLE II.
Comparing Intra- and Inter-rater Agreement Between Reviewers for Tele-otology Diagnoses From the Royal Darwin Hospital, Northern Territory, Australia Between 2010 to 2019.

	Overall	Standard Error
Average intra-rater agreement		
Attempts 1 and 2		
Percent agreement	83% (95%CI: 70–95%)	0.06
Cohen κ	0.71 (95%: 0.50–0.91)	0.10
Average inter-rater agreement by ground truth classification (Rater 1 vs. Rater 2)		
Overall		
Percent agreement	81% (95%CI: 73–89%)	0.04
Cohen κ	0.78 (95%CI: 0.69–0.87)	0.05
Normal aerated ear/no middle ear disease		
Percent agreement	88% (95%CI: 75–100%)	0.06
Cohen κ	0.83 (95%CI: 0.63–1.00)	0.09
AOM without perforation		
Percent agreement	56% (95%CI: 29–84%)	0.13
Cohen κ	0.41 (95%CI: 0.05–0.78)	0.17
AOM with perforation		
Percent agreement	100%	-
Cohen κ	1.00	-
OME		
Percent agreement	82% (95%CI: 69–95%)	0.06
Cohen κ	0.73 (95%CI: 0.54–0.92)	0.09
ETD		
Percent agreement	82% (95%CI: 55–100%)	0.12
Cohen κ	0.64 (95%CI: 0.09–1.00)	0.24
COMwAP		
Percent agreement	100%	-
Cohen κ	1.00	-
COMwDP		
Percent agreement	100%	-
Cohen κ	1.00	-

Agreement—proportion of agreement within and between raters, κ—Cohen kappa (proportion of agreement beyond chance), otitis media with effusion (OME), chronic suppurative otitis media with active perforation (COMwAP), chronic otitis media with dry perforation (COMwDP), Eustachian Tube Dysfunction (ETD).

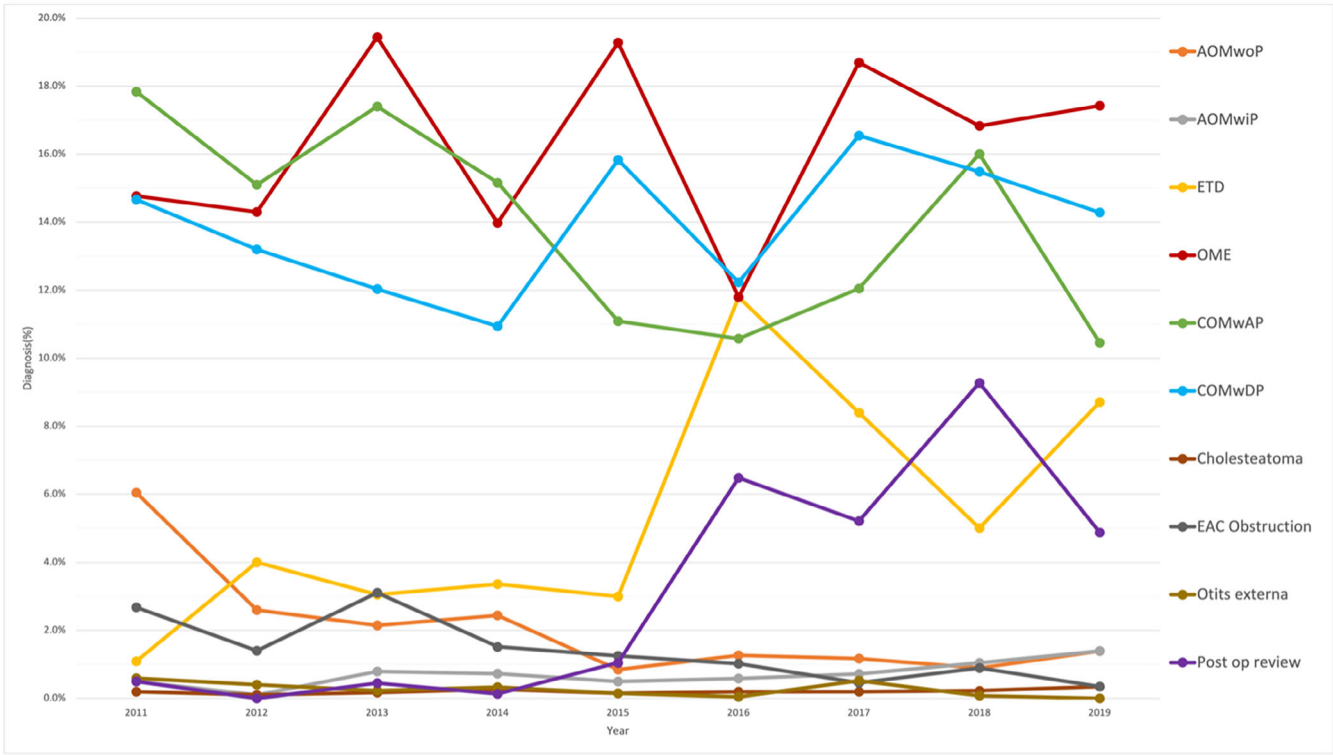

Fig. 1. Acute otitis media without perforation (AOMwoP), acute otitis media with perforation (AOMwiP), otitis media with effusion (OME), chronic suppurative otitis media with active perforation (COMwAP), chronic otitis media with dry perforation (CSOMwDP), Eustachian Tube Dysfunction (ETD), otitis externa (OE), external acoustic canal (EAC) obstruction. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

TABLE III.
Distribution of Ear Disease by Age Group.

	Total		Age ≤3 Years		Age 4 to 6 Years		Age 7 to 16 Years		Age ≥ 17 Years	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
No ear disease	4442	35.9%	233	23.9%	480	30.2%	2971	37.9%	758	38.2%
Healed perforation	952	7.7%	12	1.2%	55	3.5%	650	8.3%	235	11.8%
Postoperative review	300	2.4%	2	0.2%	9	0.6%	182	2.3%	107	5.4%
AOMwoP	241	1.9%	98	10.1%	48	3.0%	93	1.2%	2	0.1%
AOMwiP	82	0.7%	23	2.4%	18	1.1%	34	0.4%	7	0.4%
ETD	681	5.5%	58	6.0%	121	7.6%	447	5.7%	55	2.8%
OME	2047	16.5%	302	31.0%	462	29.1%	1209	15.4%	74	3.7%
COMwAP	1746	14.1%	144	14.8%	214	13.5%	1058	13.5%	330	16.6%
COMwDP	1737	14.0%	90	9.2%	164	10.3%	1091	13.9%	392	19.8%
Cholesteatoma	24	0.2%	1	0.1%	1	0.1%	11	0.1%	11	0.6%
Tympanostomy tube in situ	94	0.8%	9	0.9%	11	0.7%	69	0.9%	5	0.3%
Tympanostomy tube extruded	7	0.1%	0	0.0%	1	0.1%	6	0.1%	0	0.0%
Otitis externa	32	0.3%	1	0.1%	3	0.2%	20	0.3%	8	0.4%

Acute otitis media without perforation (AOMwoP), acute otitis media with perforation (AOMwiP), otitis media with effusion (OME), chronic suppurative otitis media with active perforation (COMwAP), chronic otitis media with dry perforation (COMwDP), Eustachian Tube Dysfunction (ETD), otitis externa (OE).

Children ≤3 years of age were more likely to present with AOM with or without perforation (OR: 28.5, 95%CI: 13.1–62.1, $p < 0.001$), OME (OR 10.7, 95%CI: 7.6–14.8, $p < 0.001$), or ETD (OR 2.9, 95%CI: 1.8–4.5, $p < 0.001$) than individuals ≥17 years of age. The likelihood of COM with active or dry perforation was greater among individuals ≥17 years (OR 2.1, 95%CI: 1.6–2.6, $p < 0.001$) and 7 to 16 years (OR 1.3, 95%CI: 1.1–1.6, $p = 0.006$) than children ≤3 years of age.

Management

CNCs initiated oral or topical antibiotics in 53.7% of individuals with COMwAP and AOM with perforation. Otolaryngologists recommended surgical intervention in 27.7% of all cases, consisting of myringoplasty (78.8%), adenoidectomy and myringotomy ± insertion of tympanostomy tubes (12.4%), myringotomy with insertion of tympanostomy tubes (7.9%), examination under anesthesia (0.6%), and middle ear exploration/mastoidectomy (0.3%).

Frequency of Ear Disease Between First and Second Assessments

Among the 1596 individuals who received two tele-otology assessments, 14.9% were ≤3 years old, 27.2% were 4–6 years old, 52.0% were 7–16 years old, and 5.9% were ≥ 17 years old at their first assessment. The mean time between the two assessments was 634 days (interquartile range: 659 days). Table S1 summarizes the distribution of ear disease across the two assessments.

At the second assessment, 39.1% had new onset middle ear disease, and among those, 41.9% had worse hearing than at their first assessment. Of those with a normal first assessment, 16.9% had OME and 8.4% had ETD at the second assessment, with 7.8% experiencing worse hearing.

Among individuals with AOM at the first assessment, 39.6% were prescribed oral antibiotics and 13.2% received topical antibiotics. At the second assessment, 50.9% had OME, 37.7% had no middle ear disease, 5.7% had ETD, and 3.8% had recurrent AOM.

For those with OME at the first assessment, 46.6% presented with OME at the second assessment, and 17.6% presented with worse hearing. Among those with recurrent OME, 36.0% received a surgical recommendation at the second assessment.

For individuals with ETD at the first assessment, 34.2% had OME at the second assessment, with 22.7% experiencing worse hearing. Among those with recurrent ETD, 16.7% had worse hearing at the second assessment.

Most individuals (87.6%) with a TM perforation identified at the first assessment had a recurrent/persistent TM perforation at the second assessment. Cases with COMwAP at the first assessment showed 51.8% with recurrent/persistent actively discharging perforation and 30.8% with a dry perforation at the second assessment. Cases with COMwDP at first assessment had 46.3% dry perforations and 35.5% progressed to COMwAP at the second assessment.

For suppurative OM treatment at the first assessment, 5.7% received oral antibiotics and 59.9% had topical antibiotic ear drops. At the second assessment, 55.2% experienced no change in hearing, 20.6% experienced worse hearing, and 24.1% experienced hearing improvement.

DISCUSSION

The effectiveness of telehealth has been demonstrated across various health care disciplines, showing that telehealth approaches can deliver clinical outcomes comparable to those of traditional face-to-face care.[18] Telehealth programs can improve access to tertiary services for patients in rural and remote areas, provide services for pre- and postoperative reviews, reduce travel time and associated costs, and integrate with existing primary care services.[19] This is evident in emergency telehealth services in rural and remote settings, which have proven to be cost-effective and efficient.[20] The COVID-19 pandemic significantly accelerated the adoption of telehealth, especially for delivering rehabilitation and mental health services, as it became crucial to mitigate virus transmission and ensure uninterrupted care.[21] However, the rapid integration of telehealth has not been without challenges, such as barriers to physical examinations, privacy concerns, and the need for more robust health care provider training.[22,23] These challenges are exacerbated by technical difficulties and the complexities of maintaining effective patient–clinician relationships through digital platforms, while acknowledging and maintaining cultural sensitivity.[23–25]

However, there is a paucity of information related to the prevalence of ear disease and caseload distribution associated with outreach services.[26,27] In Australia, previous studies have reported the prevalence of ear disease to range from 15 to 91% in Aboriginal and Torres Strait Islander people, depending on sampling locations, participant age, and subtype of otitis media.[28]

In the NT, previously published studies have reported the prevalence of ear disease from longitudinal reviews of neonates, vaccination programs, community and school-based screening programs, and emergency response services.[2,29–31] From these studies, the prevalence of AOM was reported as 7% to 26%, OME was reported as 26% to 31%, and COM was reported as 15% to 36%. In comparison, the referral-based NT tele-otology service reported AOM (2.6%), OME (16.5%), and COM (28.1%).

Since its inception, the tele-otology service has refined its referral process, evidenced by a decrease in the initially high number of individuals referred each year with a normal aerated middle ear, alongside an observed increase in referrals for middle ear pathology. This shift reflects both the maturation of the service and its adoption of a preventative, opportunistic assessment strategy, designed to serve a diverse Aboriginal and Torres Strait Islander population in rural and remote communities where health care resources are scarce. Some referrals that are ultimately found to have no ear disease, therefore, may represent a deliberately low threshold precautionary approach aimed at ensuring comprehensive care for a group with a known high pre-test probability of disease, preventing the escalation of potential ear conditions into more serious problems. Among those diagnosed with an ear condition, nearly one in three suffered from hearing loss, commonly for cases of chronic otitis media (COM) with or without discharge, and otitis media with effusion (OME). Over half of the individuals with suppurative otitis media received oral or topical antibiotics, and otolaryngologists recommended surgical intervention for one in every three individuals reviewed. Among those

diagnosed with an ear condition, nearly one in three suffered from hearing loss, commonly for cases of chronic otitis media (COM) with or without discharge, and otitis media with effusion (OME). Over half of the individuals with suppurative otitis media received oral or topical antibiotics, and otolaryngologists recommended surgical intervention for one in every three individuals reviewed.

The comparison in the distribution of ear disease between first and second assessments provides valuable insight into the progression and persistence of middle ear disease in Aboriginal and Torres Strait Islander people. Over one-third of individuals with ETD at the first assessment presented with OME at the second assessment. Recurrent OME at the second assessment was identified in nearly half of individuals who were found to have OME at the first assessment. These findings demonstrate that between assessments, it is common for ear disease to progress or persist, rather than to resolve. This emphasizes the importance of rigorous follow-up, surveillance, and the potential role for early surgical intervention in children with ETD and OME. For example, having a lower threshold for inserting tympanostomy tubes could be an early treatment consideration for individuals with ETD or for individuals with OME, as most will have middle ear disease at subsequent reviews. However, this needs to be balanced against the risk of introducing tube-related complications and the need for greater postoperative care in patients with tympanostomy tubes present. Organizing surgical procedures such as myringotomy and insertion of tympanostomy tubes poses significant logistical challenges for individuals living in rural and remote communities. Many patients and their families would need to travel long distances to larger urban centers for surgery, which may not always be feasible. Adherence to postoperative instructions, especially water precautions, is crucial to mitigating the risk of postoperative infections. This is particularly challenging in rural and remote areas where children may be exposed to open water and where following such precautions can vary based on values and preferences, cultural practices, and health literacy. This explains the lower-than-expected rate of tympanostomy tube insertion in this cohort, compared with an urban population.

Most children identified with tympanic membrane perforations presented with persistent perforations at subsequent reviews. One in two children with COMwAP re-presented with no improvement in ear disease status at the second assessment. For children with COMwDP, one in three developed active discharging perforations at the second review. In these cases, myringoplasty could offer a beneficial intervention by addressing the likelihood of persistent tympanic membrane perforation, improving auditory function, and reducing the risk of new or recurrent infections. However, it is important to note that myringoplasty carries risks, such as potential graft failure, postoperative infection, and the possibility of temporary or permanent hearing loss.

The strengths of this study are demonstrated by the volume of assessments collected over nearly a decade, expansive catchment of Indigenous communities from rural and remote areas, and substantial intra- and inter-rater agreement for diagnoses. In remote settings where loss to follow-up is common, efforts to establish culturally appropriate services are important to engage patients and parents/guardians, develop rapport, foster familiarity, and confidence. Providing primary care practitioners an avenue to refer patients for tertiary otolaryngology review is a priority to identify and manage ear disease to prevent long-term hearing loss and adverse complications.

This study has limitations. The scope of this study was to evaluate the initial triage and prevalence estimates ascertained from the tele-otology service in the NT, Australia. This study did not track outcomes of patients referred for face-to-face specialist reviews. The geographical remoteness of many of the communities limits the feasibility and timeliness of such face-to-face consultations, making it challenging to confirm diagnoses through direct evaluations. Future endeavors will be focused on linking tele-otology assessments to hospital admissions and surgical outcomes. Data linkage may be valuable to delineate the downstream challenges in providing specialist services requiring face-to-face interactions and the impact of tele-otology on surgical wait-lists. Although tele-otology may improve access to specialists via asynchronous assessments for diagnosis, the influx of patients requiring subsequent surgical treatment may face additional limitations in accessing these services.

Asynchronous store-and-forward telehealth approaches such as these are limited by the delays between data capture, specialist interpretation, and subsequent intervention, representing a potential missed opportunity to initiate early treatment at the point of data capture. Artificial intelligence (AI) has the potential to be integrated into existing telehealth programs.[32–34] AI-based image classification algorithms could be developed to support rural and remote health care workers classify ear disease from digital video otoscopy and triage the appropriate clinical pathway.[35] For example, health care workers could be trained to perform otoscopy and upload images into an AI-based tool either directly linked with the otoscope, accessed via smartphone or desktop applications, or cloud-based models where Internet access is available.[36,37] These advancements would support improved triage in frontline settings where immediate access to tertiary services is limited. AI tools could support surveillance to improve allocation of resources in high-demand areas. Otolaryngologists could review the AI-generated reports to establish prediction models that anticipate care needs and receive red flag notifications to initiate alerts for children who warrant urgent review.

CONCLUSION

Since 2011, a tele-otology service in NT, Australia has conducted 13,726 ear exams on 3,950 Aboriginal and Torres Strait Islander individuals from 93 communities, averaging 759 reviews per year. This service more commonly reviews individuals with CSOM than community screening programs and audiology services. Substantial intra- and inter-rater agreement was found for ear disease diagnoses by metropolitan otolaryngologists using

an asynchronous, "store-and-forward" data collection workflow. The results of this review confirm that the service has made substantial progress in addressing ear disease in this critically underserved population, but key areas requiring further attention have been identified. This tele-otology service may serve as a reference for future telehealth services in rural and remote settings to optimize service delivery for ear health and hearing assessments for Aboriginal and Torres Strait Islander people.

ACKNOWLEDGMENTS

We acknowledge the traditional owners of the lands on which this research project was conducted, their spiritual relationship to the land, and their elders both past, present, and emerging. We thank the Aboriginal and Torres Strait Islander people, elders, and community councils for allowing this research to be completed. We sincerely appreciate and acknowledge the assistance of Amarjit Anand, Christian Aguilar, Jade Winiata, and the many clinicians, nurses, audiologists, health workers, and administrative staff in the ENT Department at the Royal Darwin Hospital for their efforts in collecting and managing the clinical data used for this study.

BIBLIOGRAPHY

1. Leach AJ. Otitis media in Australian aboriginal children: an overview. *Int J Pediatr Otorhinolaryngol*. 1999;49(SUPPL. 1):S173-S178.
2. Morris PS, Leach AJ, Silberberg P, et al. Otitis media in young aboriginal children from remote communities in northern and Central Australia: a cross-sectional survey. *BMC Pediatr*. 2005;5:1-10.
3. World Health Organization. Child and Adolescent Health and Development Prevention of Blindness and Deafness. Chronic Suppurative Otitis Media: Burden of Illness and Management Options [Internet]. Geneva, Switzerland. 2004 https://www.who.int/pbd/publications/Chronicsuppurativeotitis_media.pdf
4. Su JY, He VY, Guthridge S, Howard D, Leach A, Silburn S. The impact of hearing impairment on aboriginal children's school attendance in remote Northern Territory: a data linkage study. *Aust N Z J Public Health*. 2019;43(6):544-550.
5. He VY, Su JY, Guthridge S, et al. Hearing and justice: the link between hearing impairment in early childhood and youth offending in aboriginal children living in remote communities of the Northern Territory, Australia. *Health Justice*. 2019;7(1):16.
6. Gibney KB, Morris PS, Carapetis JR, et al. The clinical course of acute otitis media in high-risk Australian aboriginal children: a longitudinal study. *BMC Pediatr*. 2005 [cited 2019 Feb 19];5(1):16 http://www.ncbi.nlm.nih.gov/pubmed/15955251
7. Su JY, Guthridge S, He VY, Howard D, Leach AJ. Impact of hearing impairment on early childhood development in Australian aboriginal children: a data linkage study. *J Paediatr Child Health*. 2020 [cited 2023 May 28];56(10):1597-1606. https://pubmed.ncbi.nlm.nih.gov/32725651/
8. Aihw. Hearing Health Outreach Services to Aboriginal and Torres Strait Islander Children and Young People in the Northern Territory: 2012–13 to 2014–15. Canberra. 2015.
9. Smith AC, Dowthwaite S, Agnew J, Wootton R. Concordance between real-time telemedicine assessments and face-to-face consultations in paediatric otolaryngology. *Med J Australia*. 2008;188(8):457-460.
10. Elliott G, Smith AC, Bensink ME, et al. The feasibility of a community-based Mobile telehealth screening Service for Aboriginal and Torres Strait Islander Children in Australia. *Telemed e-Health*. 2010;16(9):950-956. https://doi.org/10.1089/tmj.2010.0045
11. Ullah R, Gilliland D, Adams D. Otolaryngology consultations by real-time telemedicine. *Ulster Med J*. 2002;71(1):26-29.
12. Smith AC. Telemedicine: challenges and opportunities. *Expert Rev Med Devices*. 2007;4:5-7.
13. Bennett RJ, Swanepoel D, Manchaiah V. Tele-audiology services in Australia: a shift in clinical practices. *Audiol Now*. 2020;81:11-13. https://www.researchgate.net/publication/344664862
14. Smith AC, Armfield NR, Wu WI, Brown CA, Perry C. A mobile telemedicine-enabled ear screening service for indigenous children in Queensland: activity and outcomes in the first three years. *J Telemed Telecare*. 2012;18(8):485-489.
15. World Medical Association. World medical association declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA*. 2013 [cited 2019 Apr 22];310(20):2191-2194. http://www.ncbi.nlm.nih.gov/pubmed/24141714
16. Leach AJ, Morris PS, Coates HLC, et al. Otitis media guidelines for Australian aboriginal and Torres Strait islander children: summary of recommendations. *Med J Australia*. 2021;214(5):228-233.
17. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;33(1):159-174.
18. Alqudah AA, Al-Emran M, Shaalan K. Technology acceptance in healthcare: a systematic review. *Appl Sci (Switzerland)*. MDPI. 2021;11:1-40.
19. Nash K, Macniven R, Clague L, et al. Ear and hearing care programs for First Nations children: a scoping review. *BMC Health Serv Res*. 2023 [cited 2023 Oct 16];23(1):1-12. https://doi.org/10.1186/s12913-023-09338-2
20. Kavanagh BE, Corney KB, Beks H, Williams LJ, Quirk SE, Versace VL. A scoping review of the barriers and facilitators to accessing and utilising mental health services across regional, rural, and remote Australia. *BMC Health Serv Res*. 2023;23(1):1060.
21. Ftouni R, AlJardali B, Hamdanieh M, Ftouni L, Salem N. Challenges of telemedicine during the COVID-19 pandemic: a systematic review. *BMC Med Inform Decis Mak*. 2022;22(1):1-21.
22. Tsou C, Robinson S, Boyd J, et al. Effectiveness and cost-effectiveness of telehealth in rural and remote emergency departments: a systematic review protocol. *Syst Rev*. 2020;9(1):1-6.
23. Mathew S, Fitts MS, Liddle Z, et al. Telehealth in remote Australia: a supplementary tool or an alternative model of care replacing face-to-face consultations? *BMC Health Serv Res*. 2023;23(1):341.
24. Kruse CS, Krowski N, Rodriguez B, Tran L, Vela J, Brooks M. Telehealth and patient satisfaction: a systematic review and narrative analysis. *BMJ Open*. BMJ Publishing Group. 2017;7:1-12.
25. Morrow A, Orr N, Nash K, et al. Parent perspectives of ear health and the relationship with Children's speech and language in the longitudinal study of indigenous children. *Children*. 2023;10(1):1-13.
26. Shein G, Hunter K, Gwynne K, et al. The O.P.E.N. Survey: outreach projects in ear, nose and throat (ENT) in New South Wales. Australian. *J Otolaryngol*. 2019;2(1):1-10.
27. Su JY, Leach AJ, Cass A, Morris PS, Kong K. An evaluation of the quality of ear health services for aboriginal children living in remote Australia: a cascade of care analysis. *BMC Health Serv Res*. 2023. [cited 2024 Apr 21];23(1):1-11. https://doi.org/10.1186/s12913-023-10152-z
28. Jervis-Bardy J, Sanchez L, Carney AS. Otitis media in indigenous australian children: review of epidemiology and risk factors. *J Laryngol Otol*. 2014;128(SUPPL.S1):S27.
29. Foreman A. The Aetiology and Prevention of Otitis Media in Indigenous Children in the Northern Territory, Australia. [Darwin, Northern Territory]: University of Sydney. 1987.
30. Roberts D, Gracey M, Spargo RM. Growth and morbidity in children in a remote aboriginal community in north-west Australia. *Med J Aust*. 1988 [cited 2023 Oct 17];148(2):68-71. https://pubmed.ncbi.nlm.nih.gov/3336337/
31. Australian Institute of Health and Welfare. Northern Territory Emergency Response Child Health Check Initiative: Follow-up Services for Oral and ear Health. Canberra. 2012.
32. D'Onofrio KL, Zeng FG. Tele-audiology: current state and future directions. *Front Digit Health*. Frontiers Media SA. 2022;3:1-11.
33. Kuziemsky C, Maeder AJ, John O, et al. Role of artificial intelligence within the telehealth domain. *Yearb Med Inform*. 2019;28(1):35-40.
34. Schünke LC, Mello B, da Costa CA, et al. A rapid review of machine learning approaches for telemedicine in the scope of COVID-19. *Artificial Intelligence in Medicine*. Vol 129. Elsevier B.V; 2022:102312.
35. Habib AR, Crossland G, Patel H, et al. An artificial intelligence computer-vision algorithm to triage Otoscopic images from Australian aboriginal and Torres Strait islander children. *Otol Neurotol*. 2022;43(4):481-488.
36. Habib AR, Kajbafzadeh M, Hasan Z, et al. Artificial intelligence to classify ear disease from otoscopy: a systematic review and meta-analysis. *Clin Otolaryngol*. 2022;47(3):401-413.
37. Alenezi EMA, Veselinović T, Tao KFM, et al. Ear portal: an urban-based ear, nose, and throat, and audiology referral telehealth portal to improve access to specialist ear-health services for children. *J Telemed Telecare*. 2023;14 (1357633x231158839). https://doi.org/10.1177/1357633X231158839 [cited 2024 Apr 21].