





ORIGINAL RESEARCH

Hearing loss increases with size but not site of tympanic membrane perforation in Aboriginal Australian children in remote locations

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Abstract

Objective: To investigate the effect of size, site, and activity of tympanic membrane (TM) perforation on hearing loss (HL) in Aboriginal and Torres Strait Islander (ATSI) children.

Design: Observational study.

Methodology: Children aged 5–18 years who identified as ATSI at seven Anangu community schools within the Anangu Pitjantjatjara Yankunytjatjara Lands and Maralinga Lands of South Australia underwent 4-frequency pure-tone audiometry (0.5, 1, 2, and 4 kHz) and video-otoscopy (VO). VO data was reviewed by surgeons for a middle ear diagnosis and VO files with TM perforations were then classified by perforation site (AS, AI, PS, PI, A, P, I) and size (<25%, 25%–50%, 50%–75%, or 75%–100%).

Results: Five hundred seventy-five VO files with matching audiological data were obtained. Active perforations (35 dBHL; 28–44 IQR) demonstrated greater HL than inactive perforations (31 dBHL; 29–39 IQR) $p = .0029$. For inactive perforations there was a significant difference between <25% and all larger perforations ($p < .0001$) whereas for active perforations the significance changed to between <25% ($p < .0001$) and 25%–50% ($p < .05$) when compared to larger perforations. When perforation site was compared within all size/activity groups, no statistically different findings were identified. In all analyses, findings did not change when individual frequencies were compared to 4-frequency pure-tone average dBHL.

Conclusion: In ATSI children from remote communities, HL is greater in ears with larger perforations and active middle ear disease but there was no relationship between perforation site and HL.

Level of evidence: Level 4.

Jack Morris and Zoe Lee are co-first authors.

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KEYWORDS

audiometry, conductive hearing loss, otoscopy, tympanic membrane perforation

1 | INTRODUCTION

According to the World Health Organization, tympanic membrane (TM) perforation rates are the highest for Australian Aboriginal and Torres Strait Islander (ATSI) children.¹ TM perforations in ATSI children become an ongoing problem into adulthood² and previous work from our group in remote ATSI communities in South Australia demonstrated perforation rates of 31%–50% with up to 30% of individuals demonstrating activity at any one time.³ TM perforations can result in hearing losses (HLs) as high as 50 dB.⁴ Within Australia, ATSI children are particularly affected as data from the Australian Bureau of Statistics showed ATSI children experienced three times the rates of chronic otitis media (COM) as non-Indigenous Australian children,³ creating a devastating public health problem and secondary educational disadvantage in this particularly vulnerable population.⁵

It has been generally accepted that HL is greater with an increase in size of the TM perforation.⁶ However, perforation site and the effect on hearing is more controversial with contradictory evidence regarding this.^{6–12} Whilst early work showed worse hearing with posteroinferior based perforations,^{13,14} others have found posterosuperior defects to be worse^{11,15} and more recent work demonstrated no difference between sites.^{4,6,7,12} Theories such as loss of the round window baffle effect resulting in phase-cancellation, as well as an increase in ossicular chain abnormalities have been proposed to explain increases in HL with posterior perforations. The association between an increase in size and severity of HL^{4,6,10,12,16} is reinforced by bio-mechanical studies confirming the progressive loss of catenary lever ratio with enlarging perforations.¹⁷

1.1 | Objectives

The aim of this study was to investigate the relationship between perforation size, site, and disease activity on HL in ATSI children in the Anangu Pitjantjatjara Yankunytjatjara (APY) Lands of South Australia. To date, no known study has investigated the levels of HL associated with perforation location and size in ATSI children. Additionally, this study aimed to provide an epidemiological snapshot of the hearing levels and severity of perforations in this high-risk and socio-economically deprived population.

2 | MATERIALS AND METHODS

This article has been prepared with reference to the STROBE checklist for cross-sectional studies.

2.1 | Dataset

Data were collected as part of a larger study looking at the effect of swimming pool use on ear health.¹⁸ Children from seven Anangu community schools were studied. The Anangu communities are located within the APY Lands and Maralinga Lands. These lands span an area of approximately 200,000 km² in the far north-west part of South Australia and are home to a population of approximately 3500–4000 people.¹⁹ Visits to the schools were facilitated by staff at the Anangu Education Service of the Department of Education (Government of South Australia). At the time of study, there was no ENT input into medical services on the Lands, essentially making this a surgically naïve and untreated dataset.

2.2 | Data collection

Pure-tone audiometry was performed at 0.5, 1, 2, and 4 kHz using Auraldomes to reduce ambient noise exposure. All audiometry was performed in a quiet location with ambient noise recorded as being within the range of 22–36 dBA.

2.3 | Video-otoscopy

Video-otoscopy (VO) footage was obtained with a WelchAllyn (Hillrom) video-otoscope recorded onto a laptop.

2.4 | Inclusion and exclusion criteria

Inclusion criteria:

1. Identifies as ATSI.
2. Aged between 5 and 18 years.

Exclusion criteria:

1. Incomplete VO footage preventing classification of middle ear disease.
2. Incomplete audiological dataset.

2.5 | Classification

VO data was reviewed by ENT Surgeons (with a previously established >90% concordance) to obtain a middle ear diagnosis (Browning classification) for all children.²⁰ VO files with a visible TM perforation

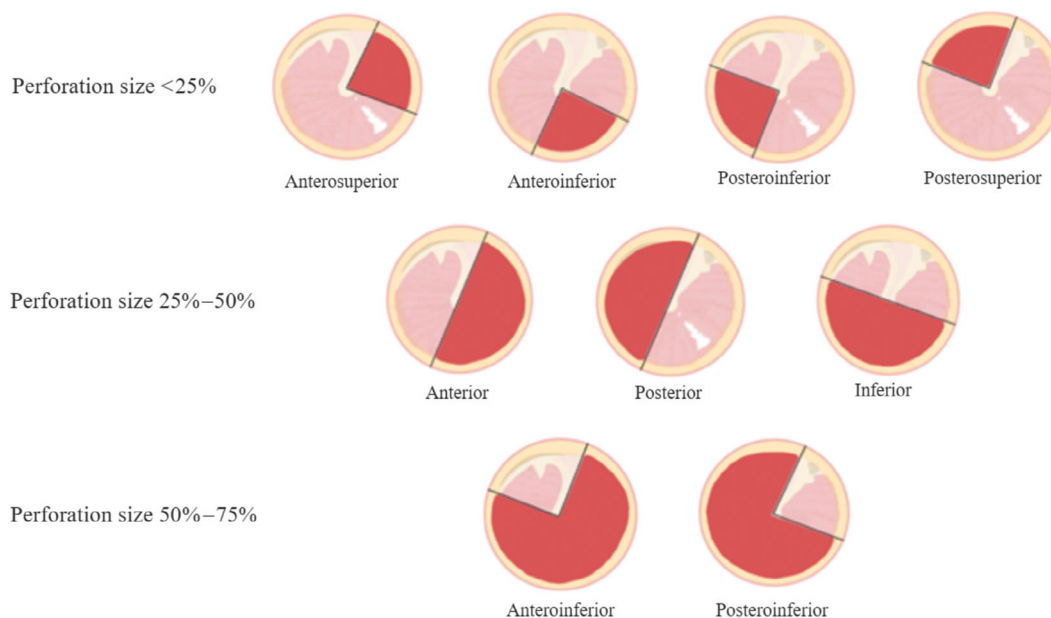


FIGURE 1 Classification of tympanic membrane perforation site according to size and site. Perforations divided into areas based around the manubrium mallei

were then analyzed by two medical students, one with a pediatric audiology background. They were trained by a senior ENT specialist on classifying perforation site and size. The students received a random sample of the same 20 VO files to classify independently. These classified files were then reviewed together with a senior ENT specialist and senior audiologist where >90% diagnostic concordance was confirmed.

Perforations were classified as either <25%, 25%–50%, 50%–75%, or 75%–100%. The site of perforations was classified depending on the perforation size (Figure 1). Perforations deemed <25% were classified by quadrants: AS: anterosuperior, AI: anteroinferior, PS: posterosuperior, PI: posteroinferior. Perforations of size 25%–50% were divided into anterior, inferior, and posterior locations. For size 50%–75%, they were classified into anteroinferior or posteroinferior locations. Perforations of 75%–100% were classified as subtotal perforations. Where perforations did not completely fit the exact regions, the closest option was chosen. Where there was any ambiguity, the VO images were reviewed by all four members of the team (the senior ENT specialist, senior audiologist, and two medical students) to obtain a final classification.

2.6 | Statistical analysis

Data were collected on an Excel spreadsheet (Microsoft) then transferred to GraphPad Prism (GraphPad Software) for statistical and graphical analysis. Classification of left and right ears were compared using Chi-squared analysis. Audiological data per classification was compared using Kruskal-Wallis test for nonparametric data with Dunn's multiple comparison test used to adjust p -values where appropriate. Percentage and dBHL were rounded to the nearest whole

number. Nonparametric data is reported as median with 25%–75% inter-quartile range (IQR) and $p < .05$ was regarded as significant. Power analysis revealed a requirement for $n = 120$ to achieve 80% power at the .05 significance level.

3 | RESULTS

3.1 | Left versus right comparison

Of the 1128 perforated ears with middle ear diagnosis obtained from the original swimming pool study,¹⁸ 575 VO files (284 left; 291 right) with matching audiological data were obtained meeting the inclusion and exclusion criteria.

Chi-squared analysis revealed no difference between left and right ears in terms of activity (wet vs. dry perforations) or size of perforations.

3.2 | Activity of perforations and HL

Active perforations (35 dBHL; 28–44 IQR) had a significantly greater HL than inactive (31 dBHL; 29–39 IQR) $p = .0029$ (Figure 2).

3.3 | Size of inactive perforations and HL

Inactive perforations demonstrated a significant difference between <25% and all other larger perforations ($p < .0001$), and between the 25%–50% and 75%–100% group ($p < .05$) but there was no significant difference between other groups (Figure 3).

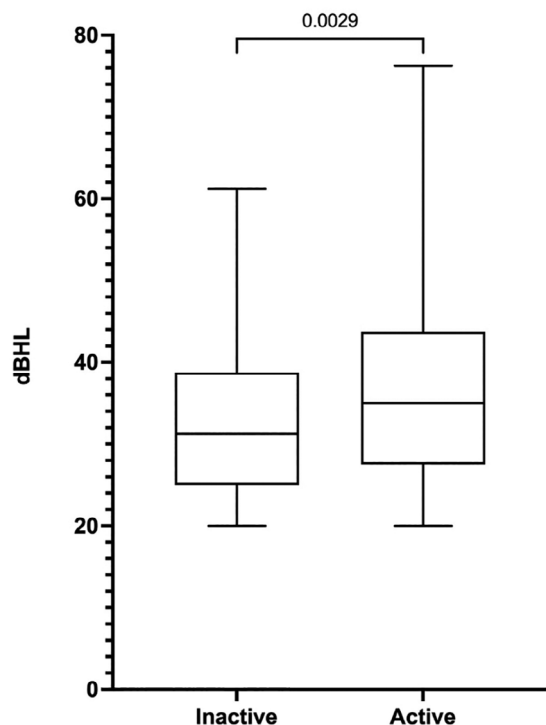


FIGURE 2 Hearing loss with active and inactive perforations (median and quartile ranges)

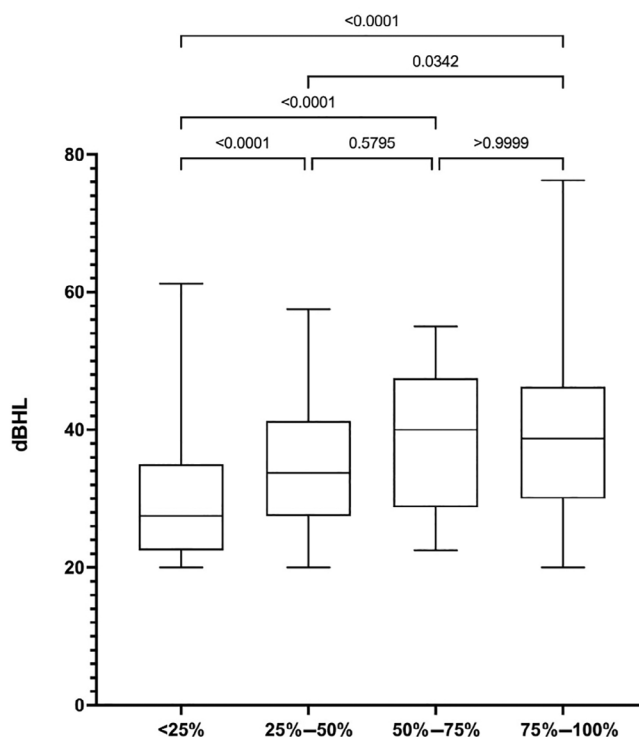


FIGURE 3 Hearing loss and size of inactive perforation (median and quartile ranges)

3.4 | Size of active perforations and HL

In contrast to the above finding, there was no significant difference between the <25% and 25%-50% groups but significance was found between both the <25% ($p < .0001$) and 25%-50% ($p < .05$) when compared the 50%-75% group (Figure 4).

3.5 | Location of perforations and HL

When perforation location was compared within all size / activity groups, there were no statistically different findings identified (Table 1, Figure 5).

3.6 | Comparison of pure-tone and 4-frequency pure-tone average (4FPTA) HL

When 4FPTA dBHL was compared to individual frequencies (0.5, 1, 2, and 4 kHz), identical results were obtained, both in terms of positive differences in perforation size and lack of significance for location within groups.

4 | DISCUSSION

This study, to our knowledge, is the first describing the relationship between size, site and activity of perforations in ATSI children. In

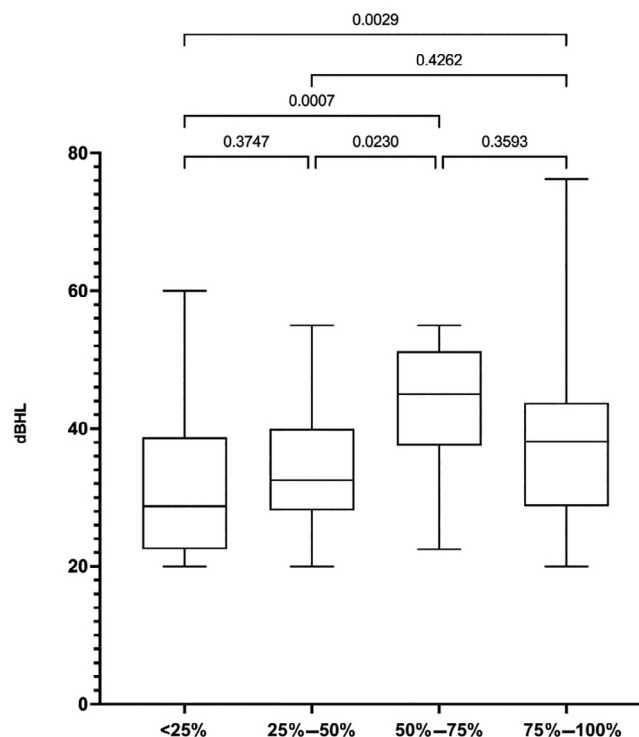


FIGURE 4 Hearing loss and size of active perforation (median and quartile ranges)

keeping with other studies,²¹ active mucosal COM created a greater HL than inactive disease. Multiple factors such as otorrhoea, mucosal hypertrophy, sclerotic change of the ossicles, and generalized inflammation have been hypothesized to explain this finding.²¹

Increasing TM perforation size also corresponded with an increase in HL. With active perforations, there was less hearing

difference with increasing size compared to the inactive group, possibly due to oedema and fluid within the middle ear. We believe the absence of a significant increase in HL in both active and inactive perforations involving the 50%–75% is due to the small number in the 50%–75% group, making this a likely Type 1 error. An increase in HL with increased TM perforation size is consistent with the consensus of both theoretical and clinical studies in the literature.^{4,6,8,10–12,16} In a study of 78 patients (107 ears) with inactive mucosal COM, perforations were classified as a percentage of total surface area using image processing software.⁸ A strong correlation was found between HL and size of perforation.⁸ A study of 300 ears divided perforations into small, medium and large using digital measurements.¹¹ The mean air-bone gap (ABG) increased with size.¹¹ This has been attributed to a decreased surface area for the amplification of sound, and a reduction in the area ratio between the TM and the stapes footplate.¹⁴ The accuracy of perforation size estimated by six physicians was compared to objective software.⁷ Between the doctors, agreement was high with kappa measures above .81 which compared favorably to the kappa of between .62 and .93 utilizing the computer.⁷

Our study found no difference in HL between frequencies across all perforation sizes and locations. This contradicts others that showed HL to be greater in the lower frequencies.^{4,6,8,11,21} We hypothesize this may be due to the unique disease processes and lack of treatment

TABLE 1 Hearing loss in inactive perforations by size and location

dBHL	<25%	25%–50%	50%–75%	75%–100%
Total	28 (23–35)	34 (28–41)	40 (29–48)	39 (30–46)
AS	27 (22–35)			
AI	27 (23–35)			
PS	29 (26–36)			
PI	27 (23–33)			
Ant	31 (26–37)			
Inf	34 (27–44)			
Post	34 (26–39)			
AI				37 (26–46)
PI				42 (32–51)

Note: Reported as median 4FPTA dBHL (25–75 inter-quartile limits). Abbreviations: AI, anteroinferior; Ant, anterior; AS, anterosuperior; Inf, inferior; PI, posteroinferior; Post, posterior; PS, posterosuperior.

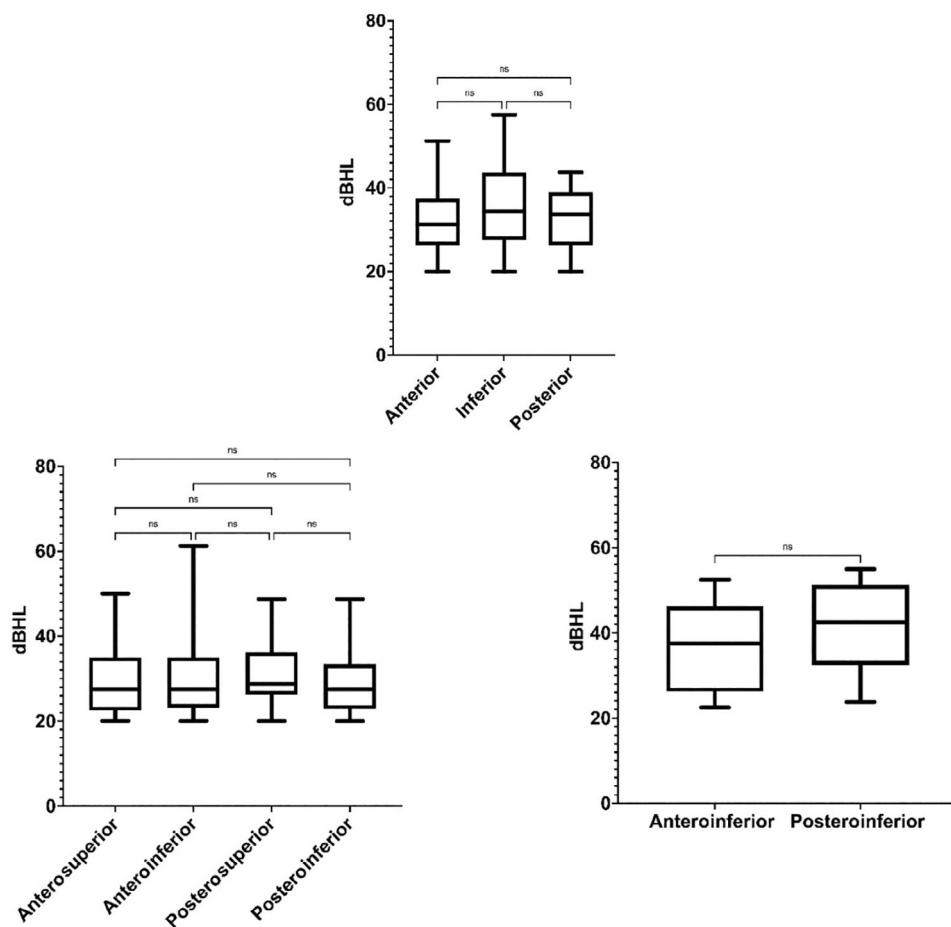


FIGURE 5 Comparison of hearing loss by location and size for inactive perforations (median and quartile ranges). Left to right: <25%, 25%–50%, and 50%–75%

in our patient group rather than the now discredited hypothesis of different anatomical factors between ATSI and Caucasian ears.

The literature regarding perforation location and hearing levels is conflicting. We found no statistically significant difference in hearing levels between perforation location and all size/activity groups. This is consistent with the findings of several studies using a variety of methods.^{6,7,12} One study used audiometric data from 56 subjects (62 perforations) and found no statistically significant difference in the ABG between anterior and posterior perforations.⁶ Another studied 38 patients (44 perforations), again with no statistically significant difference found between anterior and posterior perforations, both in terms of mean air conduction threshold, mean ABG, and frequency comparisons.¹² In 156 adult patients (172 perforations) undergoing myringoplasty for TM repair, there was no significant difference between pre-operative ABG between all quadrants for each frequency.⁷ In 35 adult Nigerian patients (42 perforations), no significant difference was found between TM perforation location and HL in patients with pure conductive HL.²² However, in patients with a mixed HL, the loss was greater for posterosuperior based perforations.²²

Several other studies also demonstrate increased HL with posterior perforations. Studies consistently utilize the manubrium mallei as the angled division between anterior and posterior.^{6-8,10,12,15,23} However, the exact classification of location varies somewhat and is not often illustrated, making comparison difficult. Statistically significant findings from a number of studies found that posterosuperior,^{11,15} posteroinferior,¹⁴ and posterior^{8,9,13} perforations were associated with greater HL. In 70 young adult males (60 perforations) posteroinferior perforations had greater HL than anteroinferior perforations, with a greater difference apparent at low frequencies.¹⁴ For perforations less than 10%, this difference was variable and inconsistent.¹⁴ More recently, in the largest study thus far, 700 patients (1400 perforations) with inactive mucosal COM were studied.¹⁵ Maximum HL was seen with posterosuperior perforations (48.6 dB) and anterosuperior perforations had the least HL (24.0 dB).¹⁵ When perforations involved two quadrants, involvement of a posterior quadrant resulted in higher HL compared to anterior quadrants but there was no significant difference between anteroinferior and posteroinferior quadrants.¹⁵ One recent study found exclusively posterior perforations had a 12% greater ABG when compared with exclusively anterior perforations, however this was only significant at 500 Hz.⁸ Another looked at 90 ears and found the mean HL in anterior perforations was 29.9 dB compared to the posterior perforation group with 44.9 dB.¹³

Many of these studies cite the “phase-cancellation effect” as a factor influencing HL for posterior perforations.^{8,9,13-15} This hypothesizes that a posterior perforation exposes the round and oval windows simultaneously to sound causing phase-cancellation and further increasing the level of HL.^{7,21} Contrary to this belief, experimental and theoretical studies by others^{4,6,24,25} found that perforation site did not affect pressure differences between the oval and round windows at all. Pressures were measured at the stapes and round windows in 11 temporal bones with no otologic disease.⁴ When anteroinferior and posteroinferior perforations were then created, no

pressure differences between the two sites were found whereas the main contributing factor to HL in TM perforations was the sound pressure difference across the TM.⁴ The same group hypothesized that wavelengths of sound <4 kHz are actually larger than the middle ear depth and therefore should not cause phase cancellation.⁶ Additionally, one other compounding paper found that posteroinferior perforations had lower mean ABG levels than anteroinferior and posterosuperior locations by 12–14 dB, thereby further contradicting the phase cancellation theory.¹¹

It is clear from the conflicting literature that there are likely to be other factors contributing to the variation in hearing levels with perforations at different locations. Involvement of the manubrium mallei has been discussed in many studies^{12,14,21} with some finding perforations with malleolar involvement showed greater HL.¹⁵ Additionally, in patients with disease lasting longer than 10 years, the average HL was greater at 52 dB compared to 36 dB with disease durations of <1 year.¹⁵

The volume of air in the middle ear and mastoid cell complex also appears to affect sound transmission. Using computed tomography¹⁰ and tympanometry,^{6,11,12} mean ABGs correlated inversely with middle ear and mastoid volume.^{6,10-12}

Perforation shape may also influence hearing levels with one study suggesting spindle-shaped perforations created greater conduction disturbance compared to circular perforations.²¹

In a multivariate logistic regression analysis on 67 patients (86 perforations) aged 10 and over size of perforation proved to be the only significant predictor of HL severity.²³

The logistical challenges of data collection in our study population due to age, remoteness, and resources mean that the variables measured in the literature cited above could unfortunately not be measured in this study.

This study has again demonstrated that children in the APY Lands are burdened with significant HL associated with potentially preventable and treatable disease. These findings assist with the qualitative estimation of HL from otoscopy based on size and site of the perforation. In resource poor areas such as the APY Lands, simple qualitative measures hold great value. HLs greater than expected based on this data may indicate damage to other structures other than the TM.

5 | CONCLUSION

To the best of our knowledge, this study is the first of its kind in school-aged children and in the ATSI population. We have demonstrated that perforation location does not significantly affect hearing levels in this population. HL was greater with activity and larger perforations. This study builds the foundation for further research into perforation characteristics and HL in this significantly affected population of children.

FUNDING INFORMATION

This study was supported by an Advanced Studies stipend from the College of Medicine and Public Health, Flinders University.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available from the corresponding author on request.

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REFERENCES

- World Health Organization. *Chronic Suppurative Otitis Media: Burden of Illness and Management Options*. World Health Organization; 2004.
- Boswell JB, Nienhuys TG. Patterns of persistent otitis media in the first year of life in Aboriginal and non-Aboriginal infants. *Ann Otol Rhinol Laryngol*. 1996;105(11):893-900.
- ABS (Australian Bureau of Statistics). *Microdata: National Health Survey, 2017-18*. ABS; 2019.
- Voss SE, Rosowski JJ, Merchant SN, Peake WT. How do tympanic-membrane perforations affect human middle-ear sound transmission? *Acta Otolaryngol*. 2001;121(2):169-173.
- 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 1):S16-S27.
- Mehta RP, Rosowski JJ, Voss SE, O'Neil E, Merchant SN. Determinants of hearing loss in perforations of the tympanic membrane. *Otol Neurotol*. 2006;27(2):136-143.
- Saliba I, Abela A, Arcand P. Tympanic membrane perforation: size, site and hearing evaluation. *Int J Pediatr Otorhinolaryngol*. 2011;75(4):527-531.
- Kolluru K, Kumar S, Upadhyay P. A study of correlation between tympanic membrane perforation size with hearing loss in patients with inactive mucosal chronic otitis media. *Otol Neurotol*. 2021;42(1):e40-e44.
- Nahata V, Patil C, Patil R, Gattani G, Disawal A, Roy A. Tympanic membrane perforation: its correlation with hearing loss and frequency affected - an analytical study. *Indian J Otol*. 2014;20(1):10-15.
- Park H, Hong SN, Kim HS, et al. Determinants of conductive hearing loss in tympanic membrane perforation. *Clin Exp Otorhinolaryngol*. 2015;8(2):92-96.
- Virk R, Kudawla K, Bansal S, Rathod R, Behera S. Correlation of site and size of tympanic membrane perforation and middle ear air space volume with magnitude of hearing loss. *Ann Otol Neurotol*. 2019;2:10-15.
- Aslier M, Özay H, Gürkan S, Kirkım G, Güneri EA. The effect of tympanic membrane perforation site, size and middle ear volume on hearing loss. *Turk Arch Otorhinolaryngol*. 2019;57(2):86-90.
- Gupta S, Harshvardhan R, Samdani S. To study the association of the size and site of tympanic membrane perforation with the degree of hearing loss. *Indian J Otolaryngol Head Neck Surg*. 2019;71(Suppl 2):1047-1052.
- Ahmad SW, Ramani GV. Hearing loss in perforations of the tympanic membrane. *J Laryngol Otol*. 1979;93(11):1091-1098.
- Rana AK, Upadhyay D, Yadav A, Prasad S. Correlation of tympanic membrane perforation with hearing loss and its parameters in chronic otitis media: an analytical study. *Indian J Otolaryngol Head Neck Surg*. 2020;72(2):187-193.
- Voss SE, Rosowski JJ, Merchant SN, Peake WT. Acoustic responses of the human middle ear. *Hear Res*. 2000;150(1-2):43-69.
- Austin D. Sound conduction of the diseased ear. *J Laryngol Otol*. 1978;92(5):367-393.
- Sanchez L, Carney AS, Esterman A, Sparrow K, Turner D. Does access to saltwater swimming pools reduce ear pathology and hearing loss in school children of remote arid zone Aboriginal communities? A prospective 3-year cohort study. *Clin Otolaryngol*. 2019;44(5):736-742.
- Australia TLBS. Our Communities. SA Health. 2022. Accessed January, 2022. <https://www.landscape.sa.gov.au/aw/visiting/our-communities>
- Browning G. Otitis media. In: Gleeson M, ed. *Scott Brown's Otorhinolaryngology: Head and Neck Surgery*. Vol 2. 7th ed. Hodder Arnold; 2008:877-911.
- Matsuda Y, Kurita T, Ueda Y, Ito S, Nakashima T. Effect of tympanic membrane perforation on middle-ear sound transmission. *J Laryngol Otol Suppl*. 2009;31:81-89.
- Ibekwe TS, Nwaorgu OG, Ijaluola TG. Correlating the site of tympanic membrane perforation with hearing loss. *BMC Ear Nose Throat Disord*. 2009;9:1.
- Choffor-Nchinda E, Djomou F, Meva'a Biouele RC, et al. Determinants of hearing loss severity in tympanic membrane perforations in a Sub-Saharan African setting. *J Laryngol Otol*. 2018;132(11):1013-1017.
- Voss SE, Rosowski JJ, Merchant SN, Peake WT. Middle-ear function with tympanic-membrane perforations. I. Measurements and mechanisms. *J Acoust Soc Am*. 2001;110(3 Pt 1):1432-1444.
- Voss SE, Rosowski JJ, Merchant SN, Peake WT. Middle-ear function with tympanic-membrane perforations. II. A simple model. *J Acoust Soc Am*. 2001;110(3 Pt 1):1445-1452.

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