Received: 1 April 2020 | Revised: 30 June 2020 | Accepted: 2 July 2020

DOI: 10.1002/lio2.432

ORIGINAL RESEARCH

Laryngoscope
Investigative Otolaryngology

Sound levels with aural suctioning: Effects of suction size, canal moisture, and distance from the eardrum

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Abstract

Objective: To determine sound levels resulting from aural suctioning of the external auditory canal.

Methods: Unweighted decibels (dB) and A-weighted decibels (dBA) sound pressure level measurements were recorded using a retrotympanic microphone in cadaveric human temporal bones. Sound measurements were made with common otologic suctions, size 3, 5, and 7 French, within the external ear canal at the tympanic membrane, 5, and 10 mm from the tympanic membrane in the dry condition. In the wet condition, the ear canal was filled with fluid and completely suctioned clear to determine sound effects of suctioning liquid from the ear canal.

Results: Sound levels generated from ear canal suctioning ranged from 68.3 to 97 dB and 62.6 to 95.1 dBA. Otologic suctions positioned closer to the tympanic membrane resulted in louder sound levels, but was not statistically significant ($P > .05$). Using larger diameter suctions generated louder dB and dBA sound levels ($P < .001$) and the addition of liquid in the ear canal during the suction process generated louder dB and dBA sound levels ($P < .001$).

Conclusions: Smaller caliber suction sizes and nonsuctioning techniques should be utilized for in-office aural toilet to reduce noise trauma and patient discomfort.

Level of evidence: 5

KEYWORDS

cadaveric temporal bone, ear canal, noise level, office suction

1 | INTRODUCTION

In-office suctioning of the external auditory canal (EAC) is a common practice in ENT clinics across the world for routine aural toilet. Cerumen impaction accounts for thousands of otolaryngology visits in the United States each year, and the use of aural suction of various sizes to remove wax and other ear canal debris is commonplace.[1] Other methods of wax removal include saline irrigation and mechanical removal using tools such as curettes and blunt hooks.

Loud noise exposures are known to cause physical and psychological stress while prolonged exposures risk permanent damage to the hearing organs. The noise levels produced by the suction tip has

Presented at the Triological Society Combined Sections Meeting, Coronado, CA, on January 23-25, 2020. Manuscript submission number #57.

previously been reported to be well over 100 dB, with patients reporting subjective alterations in hearing and even brief tinnitus.[2]

The National institute for Occupational Safety and Health (NIOSH) in 1970 established the recommended exposure limit (REL) of occupational noise exposure to be 85 dB as an 8-hour time weighted average where exposures at or above this level are hazardous.[3,4] Occupational Safety and Health Administration (OSHA) also published sound permissible exposure limit (PEL) as 90 dB as an 8-hour time weighted average.[3,5] Further distinction between the two guidelines lie in their time-intensity trade off. NIOSH is considered more conservative in that for every 3 dB increase, allowable time exposure is reduced by half; whereas OSHA allows for 5 dB increase before allowable time is reduced by half.[3-6] Our average ear cleaning encounter using constant suction typically does not exceed 30 seconds. This corresponds to 115 and 140 dB according to NIOSH and OSHA's guidelines, respectively, for a safe time-intensity exposure. Thus, it is then important to establish a model to investigate if routine office suctioning may expose patients to sound levels exceeding published safety thresholds.

A model was created using cadaveric temporal bones and placing a microphone retrotympanically closest to the underside of the tympanic membrane to measure noise levels in a closed middle ear space while using suction tips of various sizes (up to 7 French) at varying distances from the TM. We hypothesize that noise levels in the middle ear will be inversely proportional to the distance from the TM and directly proportional to the diameter of the suction tip. We performed these measurements under dry and wet conditions to determine if suctioning liquid from the ear canal contributed to higher levels of noise. Noise levels from in office suctioning may even violate NIOSH/OHSA standards or reported comfort levels.

2 | MATERIALS AND METHODS

Four human temporal bone specimens were used for the sound recording measurements. The temporal bones were specimens preserved in formaldehyde, frozen in storage and fully thawed at room temperature for at least 6 hours at the time the experiment was conducted. Each human temporal bone specimen was mounted on a temporal bone holder. Prior to conducting the sound recording measurements, meticulous care was taken to preserve the soft tissues in the bony external auditory canal and integrity of the tympanic membrane and to clean the ear canal by irrigation and suction under otomicroscopy. High-speed otologic drill was used to complete a mastoidectomy and enlarged posterior tympanotomy, taking care to maintain an intact posterior bony canal wall, posterior tympanic annulus, and chorda tympani nerve. The vertical mastoid segment of the facial nerve had to be traversed to allow passage of the microphone into the middle ear from the mastoid cavity. The recording microphone was positioned through the enlarged posterior tympanotomy into the retrotympanic space in the mesotympanum as close to the tympanic membrane undersurface as possible. The microphone was fixed into position using modeling clay compound to fill the mastoidectomy defect and create a neo-mastoid cortex (Figure 1). In this manner, the microphone was shielded from any potential external noise not coming from the external auditory canal.

Sound measurements were obtained via a sound pressure level (SPL) meter in an iPhone X device via an iOS application, AudioTools, created by Studio Six Digital. A study by Sakagami et al[6] compared this iOS Audiotools on an iPhone to two Class 1 Sound Level Meters (Rion, NL-62, and Ono Sokki, LA-4350) in measuring A-weighted SPL and

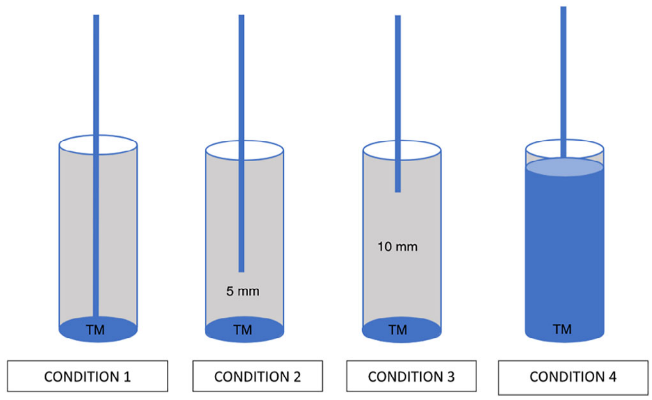

FIGURE 2 (1) Suction held at the TM in dry EAC. (2) Suction held 5 mm from TM in dry EAC. (3) Suction held 10 mm from TM in dry EAC. (4) Suction held at TM with EAC filled with water. *TM, tympanic membrane. EAC, external auditory canal

FIGURE 1 Temporal bone set up. A, Cadaveric temporal bone with mastoidectomy. B, Microphone placed into the retro-tympanic space in the mesotympanum. C, Modeling clay filling the mastoid cavity to form a neo-mastoid cortex

showed reasonable agreement with a slightly higher value of about 1 dB (A) on the iPhone app. The AudioTools app has also been used in prior audiology and otolaryngology studies, Ostegren et al[7] and Ertzgarrd et al,[8] as an affordable and accessible alternative to more expensive sound level meters in both classroom and global health settings with accurate results.

TABLE 1 Descriptive summaries of maximum sound level for each experimental condition; the row labeled "Combined" for each suction size is averaged across the three distances

				Unweighted dB		A-weighted dBA	
Size	N	Distance (mm)	Moisture	Mean	SD	Mean	SD
3	4	0	Dry	69.8	3.94	65.9	8.38
	4		Wet	80.7	5.84	80.5	6.32
	8		Total	75.2	7.45	73.2	10.43
	4	5	Dry	69.2	3.10	64.8	8.34
	4		Total	69.2	3.10	64.8	8.34
	4	10	Dry	68.3	2.18	62.6	7.20
	4		Total	68.3	2.18	62.6	7.20
	12	Combined	Dry	69.1	2.93	64.4	7.36
	4		Wet	80.7	5.84	80.5	6.32
	16		Total	72.0	6.34	68.5	9.98
5	4	0	Dry	78.5	2.13	79.2	2.48
	4		Wet	89.1	4.59	89.9	4.66
	8		Total	83.8	6.53	84.5	6.72
	4	5	Dry	75.9	4.85	75.6	6.83
	4		Total	75.9	4.85	75.6	6.83
	4	10	Dry	75.4	4.09	74.9	6.05
	4		Total	75.4	4.09	74.9	6.05
	12	Combined	Dry	76.6	3.78	76.5	5.31
	4		Wet	89.1	4.59	89.9	4.66
	16		Total	79.7	6.76	79.9	7.80
7	4	0	Dry	83.9	3.88	84.6	4.05
	4		Wet	97.0	4.67	95.1	4.23
	8		Total	90.5	8.06	89.8	6.82
	4	5	Dry	79.6	5.96	80.0	6.52
	4		Total	79.6	5.96	80.0	6.52
	4	10	Dry	78.5	6.27	78.7	7.38
	4		Total	78.5	6.27	78.7	7.38
	12	Combined	Dry	80.7	5.52	81.1	6.15
	4		Wet	97.0	4.67	95.1	4.23
	16		Total	84.8	8.96	84.6	8.41
Combined across suction sizes	12	0	Dry	77.4	6.83	76.5	9.63
	12		Wet	88.9	8.33	88.5	7.84
	24		Total	83.2	9.50	82.5	10.55
	12	5	Dry	74.9	6.25	73.5	9.37
	12		Total	74.9	6.25	73.5	9.37
	12	10	Dry	74.0	6.04	72.1	9.49
	12		Total	74.0	6.04	72.1	9.49
	36	Combined	Dry	75.4	6.36	74.0	9.41
	12		Wet	88.9	8.33	88.5	7.84
	48		Total	78.8	9.01	77.6	10.98

Suctioning was performed using Preferred Products EconoLine suction Aspirator Unit CM-61720 featuring a 1/10 hp motor capable of suctioning 22 in. Hg (560 mmHg) with flow rate up to 40 LPM. Suction trials were performed using 35 cm Hg or 14 to 17 in. Hg pressures. A McKesson PVC Suction tubing of 1/4 in. inner diameter and length of 10 ft was used along Baron otologic suction tip (V. Mueller) sizes included size #3, #5, and #7.

Sound recording measurements using each suction size (3Fr, 5Fr, and 7Fr) were made in each temporal bone under four conditions summarized in Figure 2. Condition 1 (dry): suction held at level of TM. Condition 2 (dry): suction held 5 mm from TM. Condition 3 (dry): suction held at 10 mm from TM. Condition 4 (wet): suction canal filled with water. Suctioning was limited to confines of bony EAC with intact skin. Water filled the ear canal up to the level of the bony-cartilaginous junction. Sound pressure levels were recorded for 30 seconds from 32 to 8000 Hz to encompass the test frequency range of a standard audiogram and an unweighted overall dB and an A-weighted overall dBA calculated for each condition. A-weighted dBA was included to address the varying sensitivities of the human ear to different frequencies of sound. Human ears do not hear all frequencies equally and are less sensitive to sound levels in the lower frequencies and more sensitive to sound levels at higher frequencies.

2.1 | Statistical analysis

Data were initially summarized using descriptive statistics to obtain distributional measures of each variable combination. Next, a partial-factorial (3 × 3 × 2) ANCOVA was used to evaluate each main effect and each calculable interaction; however, the dry-vs-wet condition was not replicated across each factor, and hence not all interactions could be evaluated. Owing to potential variability in canal volume being related to outcomes of interest, this variable was used as a covariate in the model. In the event main effects were significant, planned contrasts were used to evaluate multiple comparisons. Effect sizes were calculated as partial-η,[2] and significance was evaluated at $\alpha = 0.05$.

3 | RESULTS

Descriptive statistics, including N, unweighted dB, and A-weighted dBA, are provided for each experimental combination (Tables 1 and 2). There were no significant interaction effects among suction size, distance from TM, or moisture of the EAC (all $P > .50$), and hence main-effect ANCOVA models were utilized in the analyses.

3.1 | Canal volume

The canal volume for our cadaveric temporal bones ranged from 0.36 to 0.88 mL. Canal volume was positively related to sound level in all cases (r ranging from 0.20 to 0.32). Though the coefficient was not always statistically significant in bivariate analyses (*P* ranging .025-.18), it was a significant covariate across all models, and was therefore utilized as the covariate in ANCOVA models to adjust for its impact on the results (Table 2).

3.2 | Suction caliber

The unweighted dB and A-weighted dBA for the three suction sizes were statistically different during suctioning (unweighted dB, $F = 41.56$, $P < .001$; A-weighted dBA, $F = 37.02$, $P < .001$). For both dB and dBA, the 7 Fr suction produced significant higher sound levels was than the 5 Fr suction ($P < .001$) and the 5 Fr suction produced significantly higher sound levels than the 3 Fr suction ($P < .001$).

3.3 | Moisture

When moisture was introduced into the external auditory canal, there was a statistically significant increase in unweighted dB ($F = 57.42$, $P < .001$), and A-weighted dBA ($F = 36.4$, $P < .001$) sound decibels when suctioning was performed at the level of the tympanic membrane (88.9 dB, 88.5 dBA) than compared to that of a dry canal

TABLE 2 ANCOVA results with canal volume as the covariate in the model

Variable	Measurement	*F*-value	*P*-value	Effect size	Notes
Moisture	Unweighted dB	57.42	<.001	0.62	Dry < Wet (*P* < .001)
	A-weighted dBA	36.4	<.001	0.51	Dry < Wet (*P* < .001)
Suction size	Unweighted dB	41.56	<.001	0.7	3 < 5 (*P* < .001) 5 < 7 (*P* < .001)
	A-weighted dBA	37.02	<.001	0.68	3 < 5 (*P* < .001) 5 < 7 (*P* < .001)
Distance	Unweighted dB	2.63	.087	0.13	
	A-weighted dBA	2.63	.87	0.13	
Canal size (model covariate)	Unweighted dB	17.14	<.001	0.33	
	A-weighted dBA	24.89	<.001	0.42	

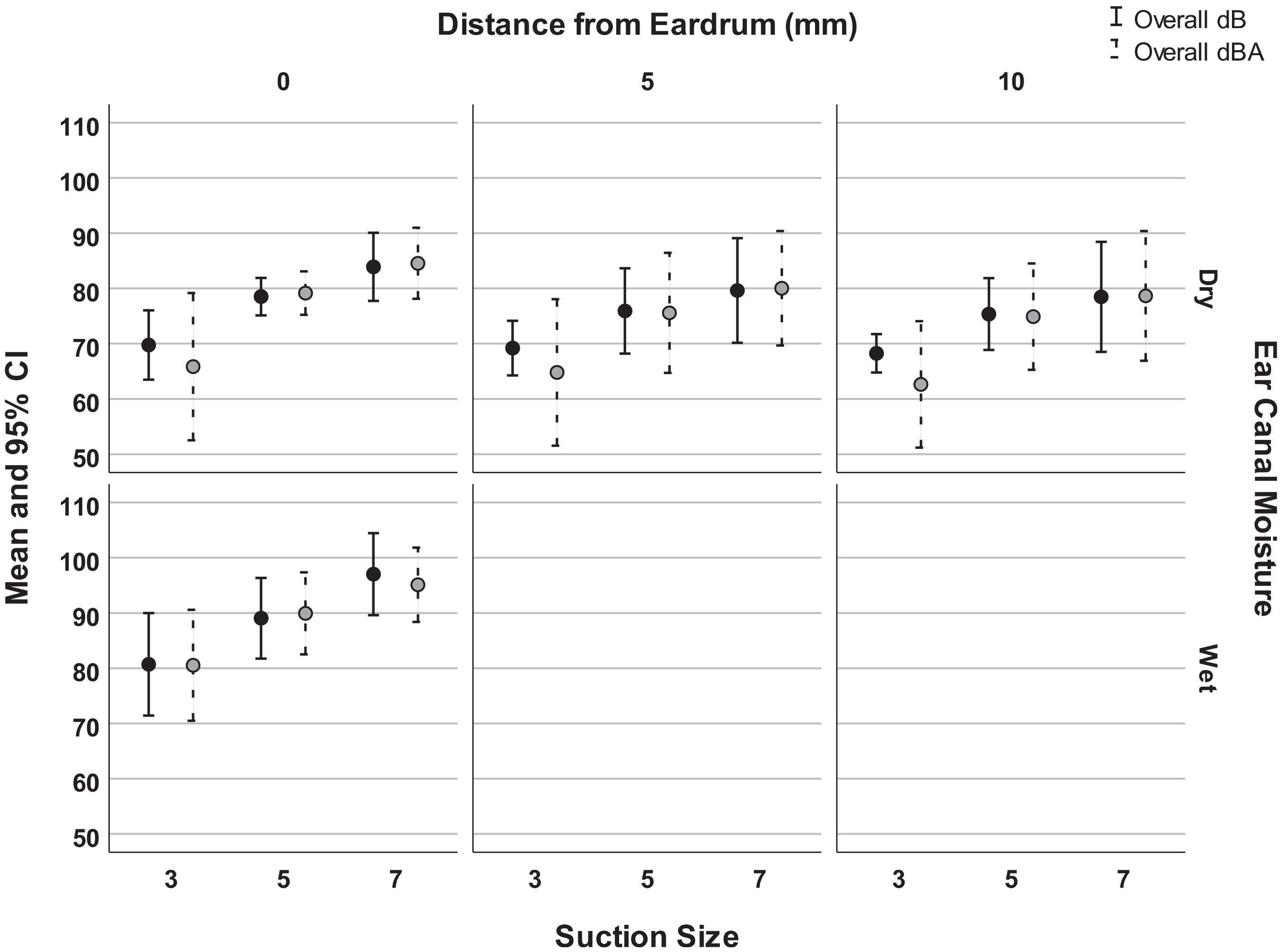

FIGURE 3 Panel plot showing the unweighted dB sound levels and A-weighted dBA sound levels for all 4 temporal bones and 95% confidence interval for each replicated experimental condition

(75.4 dB, 74.0 dBA). The difference was significant across all suction caliber sizes (*P* < .01, Figure 3).

3.4 | Distance

As the distance from the tip of the suction to the tympanic membrane increased, there were decreasing dB and dBA sound decibel levels when comparing the decibel at the level of TM (83.2 dB, 82.5 dBA) vs 5 mm from the TM (74.9 dB, 73.5 dBA) vs 10 mm from the TM (74.0 dB, 72.1 dBA). However, the difference was not statistically different (dB, $F = 2.63$, $P < .087$; dBA, $F = 2.63$, $P < .87$).

4 | DISCUSSION

Aural toilet utilizing microsuction is a common practice throughout otolaryngology practices worldwide. There have been several previous reports describing the onset of noise-induced hearing loss (NIHL) following aural microsuctioning.[1,2] Anecdotally, patients who have had their ear cleaned using microsuction have complained of subjective, post-procedural ear fullness and exacerbation of tinnitus.

Previous studies have reported on noise intensities generated by suctioning in the EAC with varying results. In the present study, we introduce additional test conditions. We developed a novel model for measuring the noise intensities encountered during aural microsuctioning at different *distances* lateral to the TM, in the *dry or wet condition*, and with *varying suction sizes* commonly used in many otolaryngology clinics. Our model differs from previous ones in that a microphone was placed medial to an intact TM, followed by closure of the mastoid cavity with modeling clay in an effort to replicate normal middle ear conditions as closely as possible. The advantages of placing the microphone in a closed middle ear space includes (1) measurement of the sound levels as close the tympanic membrane as possible, (2) measurement of sound levels without affecting the natural EAC architecture and resonance, and (3) ability to measure wet EAC conditions accurately while keeping the microphone dry. This represents a simple model that was easily reproduced in four separate cadaveric temporal bones.

The average and maximum decibel levels for each experimental condition across all cadaveric temporal bone are shown in Tables 1 and 2. Sound levels generated from ear canal suctioning ranged from 68.3 to 97 dB and 62.6 to 95.1 dBA. Our results indicate that the unweighted dB and A-weighted dBA levels were significantly different based on the size of the suction, with the 3 Fr suction intensities significantly less than the 5 Fr suction, which was significantly less than the 7 Fr suction. When evaluating the distance from the TM for each individual suction size, there was a trend toward decreased dB and dBA levels the further from the TM the suction tip was, however it was not statistically significant. The introduction of moisture into the experimental scenario significantly increased the intensities observed for each suction diameter compared to the dry condition (Figure 3). The peak intensity in our study reached up to 97 dB and 95.1 dBA for a 7Fr suction in a wet EAC at the level of the TM.

Our findings coincide with previously published results that indicate the larger the suction diameter, the louder the noise exposure. Additionally, wet conditions result in louder dB levels than dry conditions. Yin et al[9] found a significant elevation in noise levels when increasing in size from a suction tip diameter of 0.7 up to 2 mm, and their peak dB levels ranged from 100 dB with the 0.7 mm suction to 129 dB with a 5 mm suction. Their measurements were taken 0.5 cm from the suction tip while suctioning saline after mastoidectomy had been performed on a cadaveric temporal bone. Mendrygal and Roeser[2] found an increase in noise intensity with larger suction diameters as well as increasing insertion depth while suctioning air. Their measurements were taken in a Zwislocki coupler from a KEMAR manikin, and peak intensities exceeded 140 dB. Katzke and Sesterhenn[1] demonstrated that noise intensity increased as the suction tip diameter increased, up to a 9 Fr size. Their maximum values ranged from 108 to 138 dB while suctioning cerumen from the EACs of deaf human volunteers. They repeated the process using cadaveric temporal bones and did not find a significant difference in sound levels compared to the human volunteers. Peaks around 150 dB were found when suctioning silastic sheeting with 7 Fr and 9 Fr suctions, but did not occur when using the 5 Fr suction.

Another study by Nelson et al[10] found peak intensities of 88 to 111 dB when suctioning liquid from volunteer's EACs with a 5 Fr suction, and peak intensities of 77 to 93 dB when suctioning air. They performed audiometry prior to and after suctioning and did not find any significant hearing loss. Luxenberger et al[11] utilized a silicone ear model and found peak sound levels up to 118 dB when using suctions from 1.4 diameter up to 4 mm diameter, which increased to 146 dB when suctioning cerumen. They did not find a difference based on suction size, however this could be due to their relatively larger suction sizes. Hansen et al[12] also found high peak levels up to 149 dB when suctioning debris in a silicone model, but they did find a significant difference when using a 1.4 mm suction compared to a 0.7 mm suction. Snelling et al[13] attached a microphone to an aural speculum and measured sound levels during microsuctioning of volunteers. They recorded peak levels of over 120 dB with a Zoellner sucker in two patients, but state that the majority of the time for most patients was spent under 100 dB. They also report that the addition of an 18-gauge fine end to the sucker reduced intensities to a more comfortable level. They measured bone conduction thresholds before and after treatment and did not find a difference.

In the Occupational Safety and Health Act of 1970, the National Institute for Occupational Safety and Health (NIOSH) established 85 dB as the recommended exposure level to reduce hearing loss from occupational noise exposure in an 8-hour workday.[3,4] Occupational Safety and Health Administration (OSHA) also published sound permissible exposure limit (PEL) as 90 dB for an 8-hour time weighted average.[3,5] NIOSH is considered more conservative than OSHA in that for every 3 dB increase, allowable time exposure is reduced by half; whereas for OSHA, for every 5 dB increase, allowable time exposure is reduced by half.[3-6] At our institution, average ear cleaning does not exceed 30 seconds per of constant suctioning per ear, which corresponds to 115 dB and 140 dB according to NIOSH and OSHA's guidelines, respectively, for a safe time-intensity exposure. In our study, our maximum sound pressure reached 97 dB and 95.1 dBA in the setting of using a 7 Fr suction in a moist EAC, which is well below the permissible standards for both NIOSH and OSHA. Our study shows that the short duration of in-office aural suctioning is unlikely to cause permanent hearing damage, which was also shown on post-suction audiometric studies by Nelson et al[10] and post-suction bone conduction thresholds studies by Snelling et al[13] on human volunteers. Furthermore, studies have indicated that 120 to 140 dB to be considered the threshold of pain for most people.[14] However, this threshold is highly variable among individuals and factors such as age, habituation, and hyperacusis can play a role in each individual's subjective tolerance of loud noises. Otolaryngologists can reassure patients that in-aural toilet using ear suctioning does not exceed NIOSH or OSHA permissible sound levels. However, for patients with decreased protective hearing mechanisms such as old age, reduced stapedial reflex, damaged tympanic membrane, and generalized hyperacusis, otolaryngologists can limit discomfort and improve patient satisfaction by making a conscious effort to use smaller caliber suction sizes and nonsuctioning techniques for aural toilet.

One of the key differences between this study and previous studies relates to the observed noise levels during aural microsuctioning. The reported sound levels in this study, ranging from 68.3 to 97 dB and 62.6 to 95.1 dBA, are generally lower than previously reported. This discrepancy could be explained by the positioning of the microphone in our model behind the cadaveric TM instead of the ear canal directly adjacent to the suction tip. Whereas other studies have placed a microphone either in the EAC or in an open middle ear or mastoid, the microphone in this study was placed in a closed middle ear with intact TM.

The advantage to this study model includes the measurement of sound levels at the level of the TM in a closed middle ear system in a realistic, anatomically accurate cadaveric human temporal bone without alterations to the natural architecture and resonance of the EAC. No previous study has measured middle ear noise levels during suctioning in the EAC, all while in a closed system. However, this study model was limited in its inability to measure the sound levels as a result from sound transduction across the tympanic membrane and ossicular chain. Future studies that can better characterize sound level would involve placement of a hydrophone into the cochlea through a cochleostomy or round window to measure the pressure changes inside the inner ear during noise challenges. In addition, prior studies have only analyzed pure-tone audiograms in assessing for hearing loss after in-aural suctioning.[10,13] Mice studies by Kujawa et al[15] showed acute threshold shifts on Auditory Brainstem Response (ABR) at high frequencies and complete recovery of Distortion Product Otoacoustic Emissions (DPOAE) after the mice were subjected to 2 hours of acoustic stimulus at 100 dB SPL suggesting neuronal loss at high-frequency regions, despite complete OHC recovery. Thus, for future studies, obtaining more sensitive in-vivo audiometric testing in human volunteers after aural suctioning, such as Auditory Brainstem Response (ABR) and Otoacoustic Emissions (OAE), can provide more accurate information regarding threshold shifts that may not be detected by the standard audiogram.

5 | CONCLUSION

Although aural suctioning is a common ENT in-office procedure, the sound generated can be associated with discomfort and pain in certain patients. To minimize the noise trauma experienced by patients in the clinic, it may be recommended to use a smaller caliber suction size, especially when there is moisture in the EAC, and to utilize non-suctioning methods to clear cerumen whenever possible.

CONFLICT OF INTEREST

The authors above certify they have no conflict of interest or affiliations with any organization or entity with any financial or nonfinancial interest in the subject matter discussed in this manuscript.

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How to cite this article: Young A, Reeve NH, Yang A, et al. Sound levels with aural suctioning: Effects of suction size, canal moisture, and distance from the eardrum. *Laryngoscope Investigative Otolaryngology*. 2020;5:766–772. https://doi.org/10.1002/lio2.432