

An Evaluation of Electrocochleography as a Diagnostic Tool for Ménière's Disease

A thesis submitted in partial fulfilment of the
requirements for the Degree of

Master of Audiology

in the Department of Communication Disorders
at the University of Canterbury

By

Catherine J. Kalin

University of Canterbury

2010

Acknowledgments

This master's thesis could not have been completed without the help and support of many people. I would like to express my gratitude to my two primary supervisors, Dr. Emily Lin and Professor Jeremy Hornibrook, who not only served as my supervisors but also encouraged and challenged me throughout my masters study program. Their passion for research was an inspiration to me, and I would like to thank them both sincerely for the guidance and support they have given me over the past year. I would also like to thank my co-supervisor, Dr Greg O'Beirne, for his help and support with my academic writing.

I gratefully acknowledge John Gourley and the audiology staff at Christchurch Hospital who have been involved with electrocochleography recordings over the last 15 years. I would like to thank Angela Harrison at Christchurch Hospital and Glynis Whittaker at the private practice of Mr Hornibrook for the retrieval of the data files. I also wish to thank all the research participants for their contributions in this study. I sincerely thank you all for allowing me to have access to your medical files.

Finally, I would like to acknowledge the loving support of my friends and family. To my fellow postgraduate students, I am most grateful for your ongoing support, encouragement and company. I especially want to thank Mark, for his moral support, unfailing patience and encouragement. Finally, I would like to make a very special thank you to my parents, Murray and Glenys. Thank you for your support and always believing in me.

Abstract

Ménière's disease (MD) is an idiopathic inner ear disorder, characterised by episodes of vertigo, tinnitus, sensorineural hearing loss, and aural fullness in the affected ear. The relatively high variability of symptomological changes renders it difficult to confirm the MD diagnosis. The purpose of this study is to compare the diagnostic power of an instrumental method, electrocochleography (ECoChG), and two subjective methods, including the criteria based on the clinical guidelines provided by the American Academy of Otolaryngology-Head and Neck Surgery Committee on Hearing Equilibrium (AAO-HNS CHE) and Gibson's Score.

A quota sampling method was used to include subjects. A total of 250 potential MD patients who were referred to the Department of Otolaryngology at the Christchurch Hospital between year 1994 and 2009 have had their signs and symptoms documented and ECoChG testing completed. A selection of details obtained from both AAO-HNS CHE and ECoChG assessment results were examined as a chart review in regard to its function as a diagnostic tool for MD.

The between-method reliability was found to be high, with a few disagreements on individual diagnosis. Based on a receiver operating characteristic (ROC) curve analysis, the ECoChG measures were shown to be pertinent to the diagnosis of MD. It was also found that patients tested "positive", as compared with those tested "negative", tended to show higher correlations among the four key symptoms of MD and among the ECoChG measures derived from the auditory evoked responses to tone bursts at frequencies in close proximity to each other.

Table of Contents

Acknowledgments	ii
Abstract.....	iii
Table of Contents	iv
List of Figures.....	vi
List of Tables	x
Chapter One: Introduction	1
1.1 Overview.....	1
1.2 Literature Review.....	2
1.2.1 Ménière’s Disease (MD).....	3
1.2.1.1 Aetiology and Prevalence	3
1.2.1.2 Audiometric Configuration.....	4
1.2.2 Subjective Assessment of MD	6
1.2.2.1 AAO-HNS CHE Criteria	6
1.2.2.1.1 The AAO-HNS CHE Guidelines	6
1.2.2.1.2 Assessment of the AAO-HNS CHE Guidelines	11
1.2.2.2 Gibson’s Score.....	12
1.2.3 Electrocochleography.....	14
1.2.3.1 Electrocochleographic Auditory Evoked Responses.....	15
1.2.3.2 ECochG Recording Techniques	18
1.2.3.3 Acoustic Stimulus.....	19
1.2.3.4 Endolymphatic Hydrops	21
1.2.4 Magnetic Resonance Imaging.....	23
1.2.5 Treatment of MD and the Impact of Diagnosis	24
1.3 Research Question	26
1.3.1 Rationale and Importance	26
1.3.2 Aims and Hypotheses.....	26
Chapter Two: Methodology	28
2.1 Participants and Participants’ Task.....	28
2.2 Instrumentation	29
2.3 Procedure	31

2.4	Measurements	32
2.4.1	Pure Tone Audiometry Measurements.....	32
2.4.2	AAO-HNS CHE Measurements	32
2.4.3	Gibson’s Score Measurements.....	32
2.4.4	Electrocochleography Measurements	33
2.5	Data Analysis	33
2.6	Statistical Analysis.....	35
2.7	Ethical Considerations	37
Chapter Three: Results		38
3.1	Agreement between Diagnostic Tools	38
3.1.1	ROC Curves for AAO-HNS CHE Criteria and Gibson’s Score.....	38
3.1.2	Inter-method Reliability.....	41
3.1.2.1	ECochG and AAO-HNS CHE Criteria.....	42
3.1.2.2	ECochG and Gibson’s Score	44
3.1.2.3	Gibson’s Score and AAO-HNS CHE Criteria.....	46
3.1.2.4	Tone-burst and Click ECochG.....	47
3.2	Comparisons between “Positive” and “Negative” ECochG Cases.....	48
3.2.1	Relationships between Symptoms of MD.....	49
3.2.2	Hearing Loss Patterns	52
3.2.3	Relationships between ECochG Measures.....	57
3.2.4	Demographic Information.....	60
3.3	Summary of Main Findings	66
Chapter Four: Discussion.....		68
4.1	The Agreement between Diagnostic Tools.....	68
4.2	Evaluation of Electrocochleography.....	71
4.3	Findings of the Study in Relation to Previous Research.....	74
4.4	Clinical Implications.....	76
4.5	Limitations of the Study and Future Direction	76
4.6	Conclusion	77
References.....		79
Appendix 1.....		85
Appendix 2.....		89
Appendix 3.....		92

List of Figures

- Figure 1.** The waveforms (X-axis: time; Y-axis: amplitude) of the combined signals of the cochlear microphonic (CM) and summing potential (SP) in the top graph, the SP waveforms in the middle graph, and the waveform of the acoustic stimulus in the bottom graph (adapted from Ferraro & Durrant, 2002, p. 251)..... 16
- Figure 2.** A normal ECoChG trace using alternating clicks at 80 dB HL. The amplitudes of the SP and AP can be measured by either a peak-to-trough (left graph) or a baseline reference (right graph) demarcation method where the SP is subtracted from the AP (Ferraro, 2000, p. 435).....17
- Figure 3.** Upper trace illustrates an ECoChG recording in response to a 2 kHz tone burst stimulus in an ear with no endolymphatic hydrops (copied from Ferraro, 2000; p. 436). The middle trace illustrates response to a click stimulus and the lower trace response to a tone burst stimulus in an ear with endolymphatic hydrops (copied from Gibson, 2009; p.39).....20
- Figure 4.** The SP waveforms in response to a 90 dB HL stimulus at different frequencies as measured in a normal ear (left graph) and in a Ménière's ear (right graph) (copied from Gibson, 1996; p.14)22
- Figure 5.** Instrumentation setup.....30
- Figure 6.** Receiver operating characteristic (ROC) curve showing the relationship between sensitivity and 1-specificity of the Gibson's

	score test at 11 cut-off points (right to left from 0 to10) and that of the AAO-HNS CHE test at 3 cut-off points (“possible”, “probable”, and “definite”)	39
Figure 7.	Percentage of patients identified as “positive” and “negative” respectively using different diagnostic methods, including ECochG, AAO-HNS CHE criteria with only “Definite” as “positive” (AAO-Definite), AAO-HNS CHE criteria with both “Definite” and “Probable” as “positive” (AAO-Definite/Probable), and Gibson’s score with the cutt-off point at a value of 7.....	41
Figure 8.	Total, point-by-point, occurrence and non-occurrence reliability between ECochG measures and AAO-HNS CHE criteria, between ECochG measures and Gibson’s score, and between AAO-HNS CHE criteria and Gibson’s score.....	42
Figure 9.	The respective distribution of “positive” and “negative” ECochG cases across the three categories of AAO-HNS CHE criteria	44
Figure 10.	The respective distribution of “positive” and “negative” ECochG cases across different levels of Gibson’s score.....	45
Figure 11.	The respective distribution of “positive” and “negative” AAO-HNS CHE cases across different levels of Gibson’s score.....	46
Figure 12.	Number of “positive” tone burst and Click ECochG results	47
Figure 13.	Percentage of patients showing each of the four key symptoms of MD	50
Figure 14.	The respective distribution of “positive” and “negative” ECochG cases across different levels of hearing loss	53

Figure 15.	The respective distribution of “positive” and “negative” ECoChG cases across three types of between-ear contrast on hearing loss. Significantly different between-type comparisons were marked with different letters. Significantly different between-diagnosis comparisons were marked with an asterisk (“*”)	54
Figure 16.	The respective distribution of “positive” and “negative” ECoChG cases across two different levels of between-ear threshold differences.....	55
Figure 17.	Means and standard deviations of hearing threshold as measured at 0.5, 1, 2 and 4 kHz frequencies for the “positive” and “negative” ECoChG groups.....	56
Figure 18.	Means and standard deviations of the coefficient of variation (for tone burst ECoChG across frequencies) obtained from the “positive” and “negative” patients as classified by three diagnostic methods, including ECoChG, AAO-HNS CHE criteria with only “Definite” as “positive”, and Gibson’s score with the cut-off point at a value of 7.....	60
Figure 19.	Percentage of “positive” ECoChG cases in each gender	61
Figure 20.	Ethnicity of all the 250 patients included in this study	62
Figure 21.	Percentage of “positive” ECoChG cases in each age range as compared to the AAO-HNS CHE diagnosis.....	63
Figure 22.	Percentage of “positive” ECoChG cases presenting with a unilateral left or right ear or a bilateral sign of MD.....	64
Figure 23.	The number of patients identified as having bilateral Ménière’s Disease	65

Figure 24. The total number of ears tested as shown in the Gibson score
from the AAO-HNS CHE diagnosis..... 66

List of Tables

Table 1.	1972 AAO-HNS CHE Criteria for the diagnosis of Ménière’s disease (adapted from Committee on Hearing and Equilibrium, 1972; p. 1464).....	7
Table 2.	1985 AAO-HNS CHE Criteria for the diagnosis of Ménière’s disease (adapted from Committee on Hearing and Equilibrium, 1985; p. 6-7).....	8
Table 3.	1995 AAO-HNS CHE Criteria for the diagnosis of Ménière’s disease (adapted from Members of the Committee on Hearing and Equilibrium, 1995; p. 182).....	10
Table 4.	The point system of Gibson’s Score (adapted from Gibson, 1991; p. 109).....	13
Table 5.	Electrocochleography norms (adapted from Gibson, 1994).....	34
Table 6.	Formula for calculating the diagnostic power of the two subjective tests respectively as compared with ECochG diagnosis.....	36
Table 7.	Conditions given for the calculation of four types of inter-method reliability.....	37
Table 8.	Correlations (Pearson’s r) between SP/AP ratios at from Click ECochG and that from Tone-burst ECochG at 500, 1,000, 2,000 and 4,000 Hz in the “positive” (POS) and “negative” (NEG) cases classified by three diagnostic methods	48

Table 9.	Correlations (Spearman rho) between the four key symptoms in the “positive” (POS) and “negative” (NEG) cases classified by three diagnostic methods.....	51
Table 10	Correlations (Pearson’s r) between SP/AP ratios at 0.5, 1, 2 and 4 kHz in the “positive” (POS) and “negative” (NEG) cases classified by three diagnostic methods	58

Chapter One: Introduction

This study concerns the agreement on the diagnosis of Ménière's disease (MD) between an instrumental measure, electrocochleography (ECoChG), and two subjective measures, including the clinical guidelines specified by the American Academy of Otolaryngology-Head and Neck Surgery Committee on Hearing Equilibrium (AAO-HNS CHE) and the Gibson scale. This chapter provides an overview of the rationale behind the investigation, a literature review, the research question, its importance and related aims and hypotheses.

1.1 Overview

Ménière's disease is an idiopathic inner ear disorder (Menière, 1861; Ries, Rickert, & Schlauch, 1999). It is characterised by episodes of vertigo, roaring tinnitus, fluctuating sensorineural hearing loss, and a sense of aural fullness in the affected ear, with a combination of these signs and symptoms fluctuating over months and years (Sajjadi & Paparella, 2008). Vertigo can be experienced in two ways, with the sensation of oneself spinning through space being referred to as "subjective vertigo" and that of the environment spinning around oneself as "objective vertigo" (Bhatnagar, 2002). Episodes of vertigo which can last for several minutes or hours are often associated with nausea and vomiting (Hall, 2007). Fluctuating tinnitus and sensations of fullness in the ear can worsen during vertigo attacks (Valente, Hosoford-Dunn, & Roeser, 2008). These symptoms may fluctuate in frequency and severity for different individuals, resulting in difficulties in the diagnosis of MD.

The aetiology of MD has been linked to endolymphatic hydrops, with evidence from histological studies (Hallpike & Cairns, 1938; Horner, 1991). Endolymphatic hydrops refers to swelling of cochlea at the boundaries of the scala media from excessive accumulation of the endolymph (Hall, 2007). Treatment of MD can be difficult and controversial because the exact aetiology of MD is unknown and a complete remedy has not been developed. Several treatment options are available depending on an individual's symptoms and responses to previous treatments. Lifestyle changes, such as a low salt diet and avoidance of tobacco products, caffeine, alcohol, and chocolate, may be made to alleviate the symptoms before the administration of drugs and surgical intervention (Sajjadi & Paparella, 2008).

Although MD has been extensively studied clinically and experimentally, little is known about the precise pathophysiology. The diagnosis of MD is normally made using the clinical guidelines set by the AAO-HNS CHE based on a selection of signs and symptoms (Members of the Committee on Hearing and Equilibrium, 1995). Other measurements, such as Gibson's Score, electrocochleography, and more recently, magnetic resonance imaging (MRI), have also been used to assist in the diagnosis of MD (Gibson, 1990; Nakashima et al., 2009). However, the histological information and thus the confirmation of a MD diagnosis can only be obtained through post-mortem biopsies (Roeser, Valente, & Hosford-Dunn, 2000). Therefore, the administration of appropriate clinical diagnostic tools and treatment remains a challenging task.

1.2 Literature Review

This literature review provides the theoretical framework and previous findings regarding a variety of approaches in the diagnosis of MD. Specifically, this

review covers topics related to MD, AAO-HNS CHE criteria, Gibson's Score, ECochG, and MRI of the inner ear.

1.2.1 Ménière's Disease (MD)

In 1861, Prosper Ménière described the typical characteristics of MD (Menière, 1861; Morrison, 1997; Thorp & James, 2005; Sajjadi & Paparella, 2008; Vrabec, Simon, & Coker, 2007) based on the work of Pierre Flourens, along with his own observations of patients with vertigo, hearing loss, and tinnitus. Pierre Flourens surgically removed the semicircular canals in a pigeon and found the removal resulted in a loss of balance that was oriented in the same direction as the removed semicircular canal (Baloh, 2001; Flourens, 1824; Thorp & James, 2005). Although not well received at the time, Prosper Ménière concluded that the main clinical signs and symptoms of MD were tinnitus, progressive hearing loss, and vertigo attacks, and the cause was likely to be a lesion located in the semicircular canals (Thorp & James, 2005; Sajjadi & Paparella, 2008).

1.2.1.1 Aetiology and Prevalence

The aetiology of MD has been studied extensively. According to Horner (1993), endolymphatic hydrops was first discovered in the temporal bones of MD patients by Hallpike and Cairns (1938), who coined the term "endolymphatic hydrops" in referring to a swelling (edema) of the scala media within the cochlea (Hall, 2007). It has been hypothesized that the cause of the swelling was either endolymphatic pressure or the K^+ intoxication of the perilymph from the endolymph (Horner, 1991). Horner (1991) surgically induced endolymphatic hydrops in guinea pigs to investigate the effects and found both hypotheses equally plausible. According to Horner (1993), many studies with similar experimental trials have been

conducted on different animals but none have proven a definitive cause of the edema of the scala media within the cochlea.

Several estimates of the prevalence of MD have been published. These results vary broadly depending on the population studied. An estimated 513 per 100,000 was reported for a Finnish population (Havia, Kentala & Pyykkö, 2005) and 17 per 100,000 for a homogeneous Asian population (Watanabe et al., 1995). The large variations on the estimated prevalence across countries may be due to the between-study differences in the information available at the time of the research, the way subjects were assessed and selected, cultural and therefore lifestyle differences and the average age of the populations of concern (Havia, Kentala & Pyykkö, 2005). Although the prevalence of MD is generally considered unknown (Costa, Sousa & Piza, 2002), Paparella, da Costa, Fox & Yoo (1991) noted that MD was more common in adults in their fourth or fifth decade of life. Vrabec, Simon, & Coker (2007), in studying the prevalence of definite MD cases based on a review of the medical records of patients seen between 2001-2003 in a hospital in the USA (Houston, Texas), also concluded from the identified 190 MD cases that the mean age of onset for MD was 45.9 years of age.

In summary, researchers have been generally consistent in the findings of the mean age of onset of MD, as well as the association between MD and endolymphatic hydrops and various risk factors, while the prevalence and the underlying pathophysiology of MD remain largely unclear.

1.2.1.2 Audiometric Configuration

Hearing loss in those with MD often occurs unilaterally but can also occur bilaterally (Thorp & James, 2005). Sensorineural hearing loss (SNHL) was found to fluctuate in the early stages of MD, with the loss typically starting from low

frequencies. After 8-10 years from onset, the hearing loss usually stabilizes at a moderate to severe sensorineural hearing loss (Vrabec, Simon, & Coker, 2007). Audiometric configuration has been studied in relation to endolymphatic hydrops, a major feature of MD (Horner, 1991). For example, Horner (1993) found in guinea pigs that induced endolymphatic hydrops resulted in a peaked audiometric configuration. The loss of hearing sensitivity was found to start at low frequencies, progress to high frequencies, showing a mid frequency 'peak' in the audiogram, and finally include mid frequencies at a later stage. In a retrospective study, Ries, Rickert and Schlauch (1999) compared the audiometric configurations of individuals with unilateral MD, those with unilateral acoustic tumor, and those from a general clinical population of an audiology clinic. It was found that 17% (13.6/80) of the participants with unilateral MD showed a peaked audiometric configuration in one ear and flat audiometric configuration in the other. In comparison, 12.5% (7/56) of participants with unilateral acoustic tumor and 9% (8/89) of participants in the general clinical population also presented with a peaked audiometric configuration. This finding indicated that individuals with MD had a higher incidence of peaked audiometric configuration but it could not be concluded that the peaked audiometric configuration was pathognomonic of MD. Furthermore, McNeill, Cohen and Gibson (2009) examined the hearing change of six individuals with MD before, during and after attacks of vertigo. The study showed that five of the subjects showed less than a 10 dBHL change in their audiometric hearing threshold at all frequencies tested before, during and after an attack of vertigo. One patient showed some deterioration of hearing before the vertigo attack only. It was, therefore, suggested that hearing thresholds did not alter significantly before, during or after vertigo attacks for individuals with MD.

1.2.2 Subjective Assessment of MD

Several methods can be used to assist in the assessment of individuals with MD. In common practice, a subjective assessment following AAO-HNS CHE criteria or the Gibson scale is used for the diagnosis of MD. For diagnostic purpose, these subjective assessment methods can be used on their own or in combination with an instrumental approach, such as ECoChG measures.

1.2.2.1 AAO-HNS CHE Criteria

The AAO-NHS CHE approach to the diagnosis of MD is summarised in a set of guidelines that were published to standardise the diagnostic criteria. These guidelines were first published in 1972, and then revised in 1985 and 1995 (Committee on Hearing and Equilibrium, 1972; Committee on Hearing and Equilibrium, 1985; Members of the Committee on Hearing and Equilibrium, 1995).

1.2.2.1.1 The AAO-HNS CHE Guidelines

In 1972, the first standard for MD diagnosis was established by the American Academy of Otolaryngology-Head and Neck Surgery Committee on Hearing and Equilibrium using a letter designation system to categorize various forms of patient presentations. The categorization of this method is based on the consistency of the presence of vertigo spells in relation to hearing status (Committee on Hearing and Equilibrium, 1972). The four categories with their associated descriptions are shown in Table 1. In 1985, the AAO-NHS CHE guidelines for the diagnosis of MD were revised as there were several suggestions made to improve the reporting of the symptoms. Instead of employing only qualitative descriptors as in the previous criteria, this revision incorporated the use of a formula to reflect the change of vertigo spells with the frequency of the vertigo attack taken into consideration (Committee on

Hearing and Equilibrium, 1985). The formula expresses the effect that treatment has on the vertigo spells. A ratio of the average number of vertigo attacks per month for a 24 month period following initial treatment to that for a 6 month period before treatment is calculated. Hearing is assessed using a four-frequency pure tone average (PTA) at 500 Hz, 1 kHz, 2 kHz, and 3 kHz. A change in hearing is determined by comparing pre and post-treatment PTA values. Finally, the degree of disability caused by the disease in the affected individual was noted both before and after treatment. The formula and the criteria set for different degrees of disability are shown in Table 2.

Table 1. The 1972 AAO-HNS Criteria for the diagnosis of Ménière's disease (adapted from Committee on Hearing and Equilibrium, 1972; p. 1464).

Class	Criteria
A	<ul style="list-style-type: none"> - Absence of definitive spells for described period (in addition, absence of adjunctive spells as well could be so noted) - Hearing improved (in addition, hearing improved as well as serviceable could be so noted)
B	<ul style="list-style-type: none"> - Absence of definitive spells for described period - Hearing unchanged
C	<ul style="list-style-type: none"> - Absence of definitive spells for described period - Hearing worse
D	<ul style="list-style-type: none"> - Failure of control of definitive spells

Table 2. The 1985 AAO-HNS Criteria for the diagnosis of Ménière's disease (adapted from Committee on Hearing and Equilibrium, 1985; p. 6-7).

Formula

A = average number of definitive spells per month (24 mos. after therapy)

B = average number of definitive spells per month (6 mos. before therapy)

$$(A \div B) \times 100 = \text{numerical value}$$

Numerical Value

- 0 = complete control of definitive spells
- 1-40 = substantial control of definitive spells
- 41-80 = limited control of definitive spells
- 80-120 = insignificant control of definitive spells
- 120 = worse (poorer) control of definitive spells

Disability

- No disability
 - Mild disability – intermittent or continuous dizziness/unsteadiness that precludes working in a hazardous environment
 - Moderate disability – intermittent or continuous dizziness/unsteadiness that results in a sedentary occupation, i.e. desk work
 - Severe disability – symptoms so severe that exclude gainful employment
-

In 1995, the AAO-NHS CHE guidelines were again revised in order to reflect the advancement in the knowledge gained from the research on MD. These guidelines have been used to this date. As shown in Table 3 below, The 1995 AAO-NHS CHE guideline classified the diagnosis of MD into four levels: “possible”, “probable”, “definite”, and “certain” (Members of the Committee on Hearing and Equilibrium, 1995). For a person to be diagnosed as having “possible” MD, they must have all other possible causes of vertigo excluded and have experienced either an episode of vertigo of the Ménière type, which is spontaneous rotational vertigo lasting for 20 minutes or greater (may be hours), often prostrating and accompanied by disequilibrium which may last for days. Nausea is common and horizontal or horizontal rotatory nystagmus is always present. The patient must also have no audiometrically established hearing loss or a fluctuating or fixed sensorineural hearing loss with disequilibrium but without definitive episodes. For “probable” MD, the person must show one episode of vertigo, audiometrically established sensorineural hearing loss on at least one occasion, and tinnitus or aural fullness in the affected ear, with all other possible causes of the vertigo excluded. For “definite” MD, the person must have two or more impulsive episodes of vertigo that last for at least 20 minutes in duration as well as audiometrically established sensorineural hearing loss on at least one occasion, and tinnitus or aural fullness during episodes of vertigo in the affected ear, with all other possible causes of the vertigo excluded. Finally, to have a diagnosis of “certain” MD, the person must have presented with definite MD and have post-mortem histopathologic confirmation.

Table 3. The 1995 AAO-HNS Criteria for the diagnosis of Ménière’s disease (adapted from Members of the Committee on Hearing and Equilibrium, 1995; p. 182).

Category	Criteria
“Possible”	<ul style="list-style-type: none"> - Episodic vertigo of the Ménière type without documented hearing loss, or - Sensorineural hearing loss, fluctuating or fixed, with disequilibrium but without definitive episodes - Other causes excluded
“Probable”	<ul style="list-style-type: none"> - One definitive episode of vertigo - Audiometrically documented hearing loss on at least one occasion - Tinnitus or aural fullness in the treated ear - Other causes excluded
“Definite”	<ul style="list-style-type: none"> - Two or more definitive spontaneous episodes of vertigo 20 minutes or longer - Audiometrically documented hearing loss on at least one occasion - Tinnitus or aural fullness in the treated ear - Other causes excluded
“Certain”	<ul style="list-style-type: none"> - Definite Ménière’s disease, plus histopathologic confirmation

1.2.2.1.2 Assessment of the AAO-HNS CHE Guidelines

The AAO-HNS CHE guidelines were designed to be used to formally document and diagnose MD in a patient to allow for appropriate treatment selection. The AAO-HNS CHE foundation employed evidence from the clinical research in the area of MD in the attempt to develop the best possible methods that are quantitative and reproducible in the assessment of diagnostic criteria (Monsell, 2005). A review on the MD literature by Thorp, Shehab, Bance, and Rutka (2003) showed that 79.9% of papers reviewed reported the use of the AAO-HNS CHE criteria in the diagnosis of MD. However, it was found that only 50% of those publications used the AAO-HNS CHE criteria correctly to diagnose MD. This finding revealed concerns about the way this criterion has been used clinically to diagnose a patient with MD and the accuracy of diagnosis made for some patients. Also, it has been noted that in reviewing clinical studies of MD, data is less comparable between studies if the AAO-HNS CHE criteria are not strictly adhered to (Stapleton & Mills, 2008).

Van de Heyning et al. (1997) assessed the 1995 AAO-HNS CHE criteria with a method called the Inner Ear Profile. The Inner Ear Profile, which was applicable to several inner ear disorders, included several subscales for different symptoms, quantifying a symptom without linking it to a specific diagnosis. Questions were raised regarding the validity and the added value of self-administered questionnaires such as the AAO-HNS CHE criteria and the Gibson Scale. Several conclusions were drawn from the assessment of the AAO-HNS CHE criteria. Firstly, it was pointed out that the AAO-HNS CHE method was restricted, as it only diagnosed MD when a patient might have similar symptoms but a different diagnosis. Secondly, the criteria noted some critical symptoms but did not take into account some details about the symptoms, such as the length of vertigo attacks and the severity of tinnitus and aural

pressure. Finally, the criteria were criticized as not showing the impact hearing loss had on the individual as a disability. In contrast, the Inner Ear Profile was shown to take these key measures into account when taking the symptoms of the patient. It was concluded that the 1995 AAO-HNS CHE guidelines were limited in the scope of symptom investigations for the diagnosis of MD.

A similar study by Stapleton and Mills (2008) compared the AAO-HNS CHE criteria to Prosper Ménière's original description of the disease. According to Prosper Ménière, patients who had symptoms of intermittent vertiginous episodes lasting for several minutes, along with tinnitus, aural fullness, and changes in hearing, could be diagnosed as having MD. It was found that there were three times more patients diagnosed with MD using the AAO-HNS CHE criteria, 20.8% (135/650), than using Prosper Ménière's original description of the disease, 6.9% (45/650). This finding indicated that the AAO-HNS CHE method was more sensitive and less specific than the original description in the diagnosis of MD.

1.2.2.2 Gibson's Score

Gibson's Score is a points system developed in 1991 by William Gibson (Gibson, 1990). Gibson (1990) established this method to simplify the diagnosis by looking at the interaction and dependence of the four typical components present in those with MD. These four components are: vertigo, hearing, tinnitus, and aural fullness. The score is designed to be used with the clinical history of the patient, not on the symptoms of the patient at the time of consultation. Each of these four parameters included two (for tinnitus and aural fullness) or three descriptions (for vertigo and hearing) of symptoms for the parameter. Each description is worth one point. When a description applies to a patient, a point is given. As shown in Table 4, more than one point can be gained from each parameter as long as the description

applies. Once the points have been allocated, they are added up and a score out of 10 is achieved. A score of 7 or higher indicates a diagnosis of MD (Gibson, 1990). This point system is considered a helpful clinical tool as it summarises the patient's history, with a quantification scheme giving a clearer direction of a possible diagnosis. However, as the Gibson's score is obtained based on subjective assessment, the information used to obtain the score must be considered carefully or this could be a misleading tool if not used properly.

Table 4. The point system of Gibson's Score (adapted from Gibson, 1990; p. 109).

Parameter	Description	Points
Vertigo	- Rotational vertigo	1
	- Attacks of rotational vertigo lasting over 10 min	1
	- Rotational vertigo associated/linked with one or more of: hearing loss, tinnitus or aural pressure	1
Hearing	- Sensorineural hearing loss	1
	- Fluctuating sensorineural hearing loss	1
	- Hearing loss or fluctuation associated/linked with one or more of: vertigo, tinnitus or aural pressure	1
Tinnitus	- Peripheral tinnitus lasting over 5 min	1
	- Tinnitus fluctuating or changing with one or more of vertigo, hearing loss or aural pressure	1
Aural pressure	- Constant aural pressure lasting over 5 min	1
	- Aural pressure fluctuating or changing with one or more of vertigo, hearing loss or tinnitus	1
Maximum score		10

1.2.3 Electrocochleography

Electrocochleography is the measurement of an auditory evoked response (AER) from the cochlea. An AER is a response from the auditory system elicited by an acoustic stimulus (Hall, 2007). To elicit an AER, sounds such as clicks and tones of varying intensity are played through an acoustic transducer (e.g., a TDH-39 headphone). The sound source is positioned into a rubber ring which is placed over ear canal entrance, where elastic bands hold the electrode in place resting on the auricle. In most cases, the greater the intensity of the sound, the larger the AER will be because the energy ratio between the acoustic signal and environmental noise ratio will increase. The activity of the auditory system in response to the acoustic stimulus can be measured at several specific sites on the head with electrodes. Four electrodes, are typically placed on the earlobes, forehead and down the external auditory meatus (Hall, 2007). This corresponds to positions Fp, A1, and A2 respectively according to the International 10-20 System of electrode placement (Jasper, 1958). The differential recording is obtained from the electrodes placed on the two linked earlobes (A1 or A2) and the electrode down the external auditory meatus. The other forehead electrode (Fp) is the ground electrode.

The AER responses can also be obtained using other electrophysiological techniques for different assessment purposes, such as the auditory brainstem response (ABR). The ABR assesses the auditory pathway at the auditory nerve and brainstem structures (Hall, 2007). The ABR is a useful diagnostic tool for assessment of conductive hearing loss, sensorineural hearing loss, and retrocochlear pathology (Burkard & Secor, 2002). The test involves the patient quietly resting while electrodes attached to the head measure the brain activity. The sound stimulation through clicks, tone bursts, or chirps delivered to the external auditory meatus

normally elicits an AEP in those with a functioning auditory pathway (Hall, 2007). This test is used clinically in infants to obtain hearing thresholds and in adults to rule out retrocochlear pathology. As the ECochG method is the instrumental method related to the assessment of MD, it is described in detail as follows.

1.2.3.1 Electrocochleographic Auditory Evoked Responses

The ECochG waveform represents the amplitude of the AER over time. The AER arises within the first two or three milliseconds after a sudden acoustic stimulus is activated. Originating from the cochlea and the eighth cranial nerve, the normal AER consists of three components, the cochlear microphonic (CM), summing potential (SP), and the compound action potential (AP).

The CM signal, which is present throughout the whole duration of an acoustic stimulus, is an alternating current (AC) electrical potential. The CM is predominantly generated by the outer hair cells of the cochlea (Patuzzi, Yates & Johnstone, 1989a). The CM signal reflects the instantaneous displacement of the basilar membrane in response to an acoustic stimulus, reflecting the stimulus waveform (Ferraro, 2000; Ferraro & Durrant, 2002; Gibson, 1996). The displacement of the basilar membrane results in the process of mechano-electrical transduction (MET), which occurs in both the outer hair cells and inner hair cells (Yost, 2007). The CM potential can best be described as the extracellular analogue of the AC receptor current, which is carried by potassium (Patuzzi, Yates & Johnstone, 1989b).

Another observable part of the ECochG waveform is the SP, which is the least understood cochlear potential. Both CM and SP are stimulus-induced, generated by the hair cells of the cochlea in response to an acoustic stimulus (Ferraro, 2000; Ferraro & Durrant, 2002). However, while the CM reflects the displacement of the basilar membrane generated by the activity of the outer hair cells, the SP is considered to be

normally generated by the inner hair cells of the cochlea (Ferraro, 2000; Hall, 2007). The SP is a direct current (DC) response, and thus representing the stimulus envelope (Ferraro, 2000; Hall, 2007). The SP arises from the asymmetric transfer function of the inner hair cells and, as shown in Figure 1, appears as a shift in the baseline from CM.

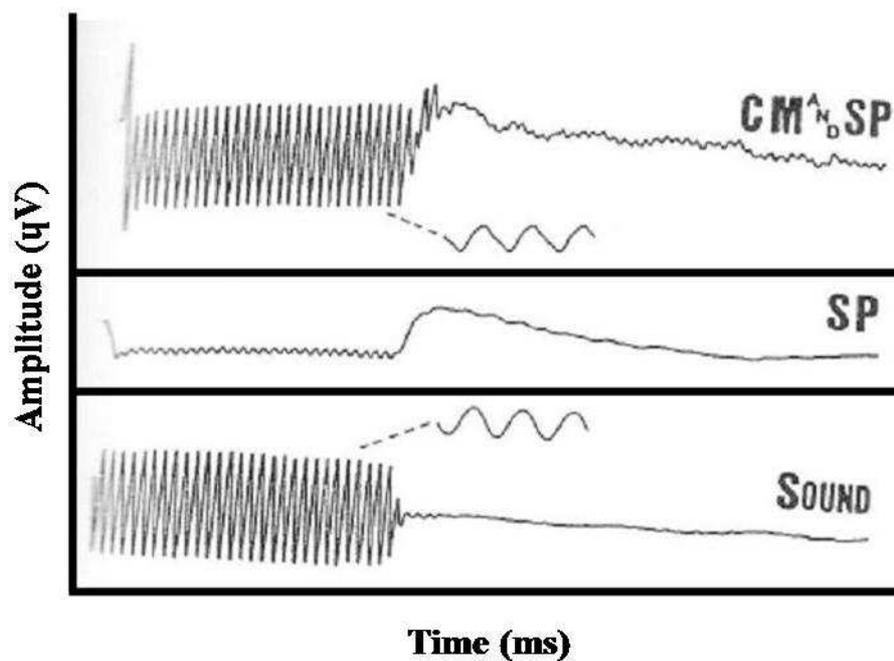


Figure 1. The waveforms (X-axis: time; Y-axis: amplitude) of the combined signals of cochlear microphonic (CM) and summing potential (SP) in the top graph, the SP waveforms in the middle graph, and the waveform of the acoustic stimulus in the bottom graph (adapted from Ferraro & Durrant, 2002; p. 251).

The AP is produced by fibres within the distal (cochlear) portion of the eighth cranial (auditory) nerve (Hall, 2007). The compound AP signal represents a collective response resulting from numerous auditory nerve fibres firing synchronously (Ferraro & Durrant, 2002). The AP is usually larger than the SP, with

a latency of approximately 1.5 ms (Hall, 2007). As shown in Figure 2, measurements commonly made on the ECoChG waveforms are the amplitudes of the SP and AP components, using either a peak-to-trough or a baseline reference demarcation method (Ferraro, 2000).

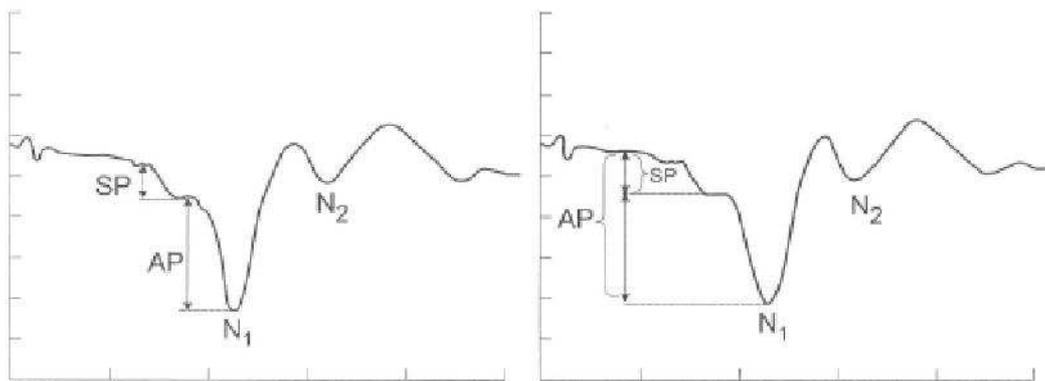


Figure 2. A normal ECoChG trace using alternating clicks at 80 dB HL. The amplitudes of the SP and AP can be measured by either a peak-to-trough (left graph) or a baseline reference (right graph) demarcation method where the SP is subtracted from the AP (Ferraro, 2000; p. 435).

It is noteworthy that the CM, along with stimulus artefact, may conceal some of the components at the beginning of the ECoChG waveforms, making interpretation difficult. To overcome this problem, which may interfere with the differentiation between CM and neural response, an alternating polarity stimulus can be employed. It has been found that the use of an alternating polarity stimulus will cancel the stimulus dependent CM, making the ECoChG waveform easier to interpret (Hall, 2007).

1.2.3.2 ECochG Recording Techniques

There are two common approaches to ECochG recording: transtympanic (TT) and extratympanic (ET). The TT ECochG method involves a recording needle electrode being placed down the ear canal and through the tympanic membrane to rest on the promontory of the cochlea (Ferraro & Durrant, 2002). The main advantage of this recording technique is the close proximity of the recording needle electrode to the cochlea, which enables large ECochG response waveforms to be obtained with a minimal signal averaging required (Ferraro & Durrant, 2002; Ge & Shea, 2002). However, there are several limitations to this method. The TT ECochG method is an invasive technique and requires a physician to place the recording needle electrode. This can restrict the test to medical settings, and consequently make it an expensive test to perform. In addition, even with local anaesthesia, the penetration of a needle through the tympanic membrane can be a painful experience for the patient (Bohlen, Arenberg & Gibson, 1990; Ferraro & Durrant, 2002).

The ET ECochG method is less invasive, with an electrode resting on the tympanic membrane or against the skin of the external auditory meatus (Bohlen, Arenberg & Gibson, 1990; Ferraro & Durrant, 2002). The advantage of the ET ECochG method is that it is more tolerable for the patient and does not require a physician present for the recording (Ferraro & Durrant, 2002). However, the ET ECochG method requires more signal averaging and yields waveforms with a lower magnitude than the TT ECochG method, leading to a poorer signal-to-noise ratio and thus greater difficulties in the interpretation of the recorded signals (Bohlen, Arenberg & Gibson, 1990).

Bohlen, Arenberg & Gibson (1990) compared the TT ECochG and ET ECochG methods by testing a total of 70 ears over a period of 18 months, with each

ear's recordings obtained from both methods on the same day. Patients were asked to rate the comfort of each method during insertion, while the test was conducted, and during extraction of the electrode. The majority of patients (70%) reported no difference in the relative comfort between the two methods. Based on an analysis of the recorded signals, the authors reported that the TT ECoChG method, as compared with the ET ECoChG method, yielded a more reliable and reproducible output signal and a significantly greater amplitude.

1.2.3.3 Acoustic Stimulus

To elicit an ECoChG AER, both clicks and tone burst stimuli of varying intensity are separately played through an acoustic transducer and the response is recorded from an electrode (Gibson, 1991; Hall, 2007). Each type of stimuli serves a different purpose. Clicks evoke a clear action potential due to their sharp onset but can cause acoustic ringing and distort the SP envelop unpredictably. Tone bursts of longer duration enhance the differentiation between SP and AP allowing for accurate measurements (Gibson, 1991). An illustration of the ECoChG waveforms in response to these two types of acoustic stimuli is shown in Figure 3.

In a study by Gibson (1993), a 1 kHz tone burst and a click were compared for the diagnosis of endolymphatic hydrops, along with his points scoring system for the clinical diagnosis of MD (Gibson's Score). The TT ECoChG method was used to test 42 normal ears, 48 sensory ears with sensorineural hearing loss, and 80 Ménière's ears. With the TT ECoChG method, the 1 kHz tone burst was found to result in a higher accuracy level than the click in detecting MD. In a later study by Ge and Shea (2002), TT ECoChG recordings using tone bursts and clicks were made for 2,421 ears from May 1990 to April 2000. It was found that tone bursts had the advantage of

frequency selectivity and could show the degree of endolymphatic hydrops at specific turns of the cochlea.

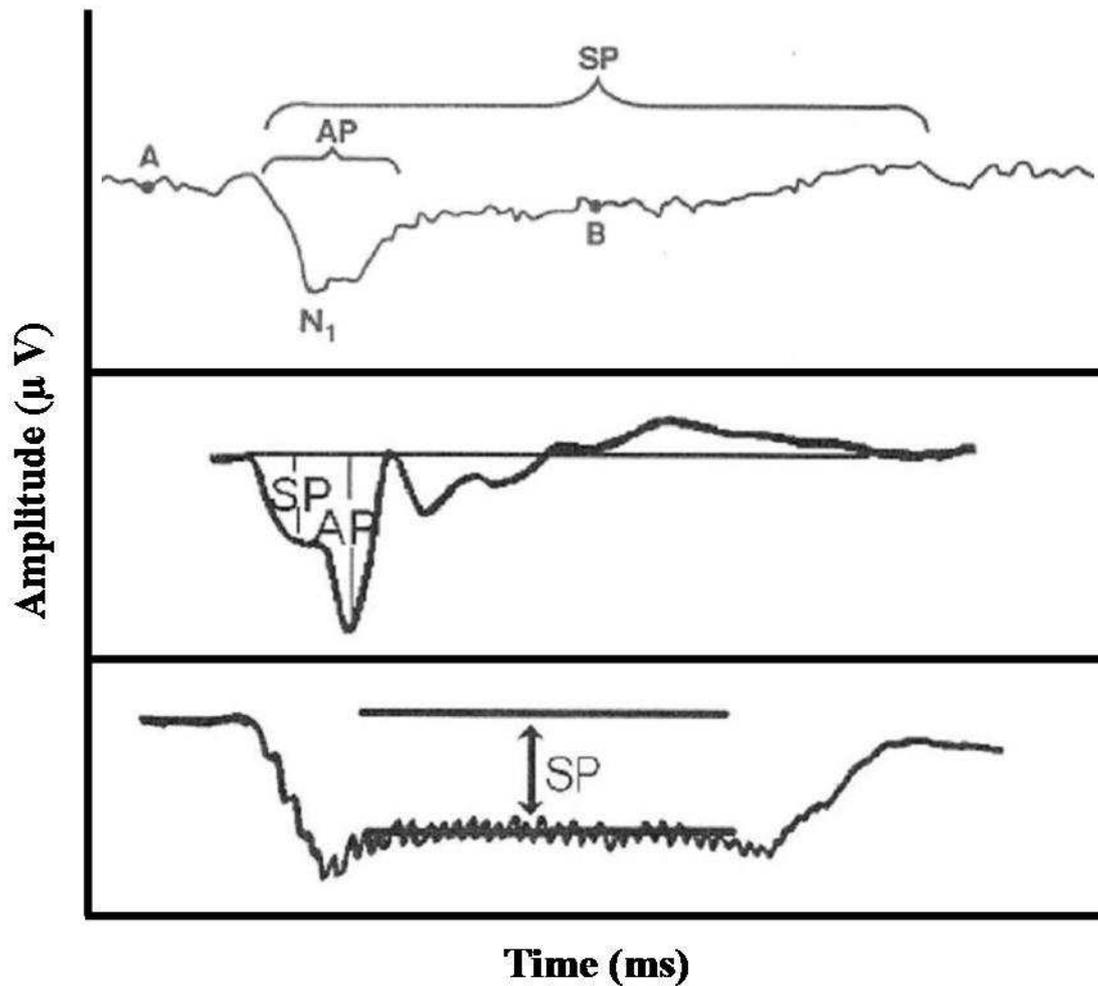


Figure 3. Upper trace illustrates an ECoG recording in response to a 2 kHz tone burst stimulus in an ear with no endolymphatic hydrops (copied from Ferraro, 2000; p. 436). The middle trace illustrates response to a click stimulus and the lower trace response to a tone burst stimulus in an ear with endolymphatic hydrops (copied from Gibson, 2009; p. 39).

1.2.3.4 *Endolymphatic Hydrops*

Endolymphatic hydrops is an inner ear pathology that can be identified at post-mortem. On examination of the temporal bones, swelling is seen in the endolymphatic spaces (Horner, 1993). This pathology is seen with several clinical disorders, including otitis media, meningitis, otosclerosis, trauma, and MD (Paparella, 1991). However, endolymphatic hydrops appears to be a consistent feature of MD and is thus considered the primary pathology of MD (Horner, 1991).

Endolymphatic hydrops is thought to change the ECochG waveforms by increasing the magnitude of the SP in response to clicks and tone bursts, creating an abnormally large potential as illustrated above in Figure 3 (Gibson, Moffat & Ramsden, 1977; Gibson, 1996; Conlon & Gibson, 2000). The effect of endolymphatic hydrops on ECochG measures has been demonstrated (Patuzzi, 1996, 2009). In a normally functioning inner ear, the inner hair cell (IHC) operating point is close to scala tympani (ST) because the hair bundles are velocity coupled. An estimated 10-20% of the mechano-electrical transduction (MET) channels are open at rest in the IHC. Because the stereocilia of the outer hair cell (OHC) are displacement coupled, the OHC operating point is more central, with approximately 40-50% of the MET channels being open at rest.

With endolymphatic hydrops, the displacement of the basilar membrane towards ST moves the OHC operating point closer to that of the IHCs. This results in an increase of DC component in the OHC receptor current, adding the OHC SP to the IHC SP. Furthermore, as there are three times as many OHCs as IHCs, the SP magnitude increases greatly. On the other hand, the amplitude of the compound AP is decreased. Most likely this is because of an OHC motor loss, which reduces the efficiency of the MET to electromechanical transduction (EMT) active process.

Asai and Mori (1989) tested eight patients with MD using ET ECoChG and reported that the amplitude change of the AP decreased with an increase of hearing threshold at high frequencies (2-8 kHz), while at low frequencies (0.25-1 kHz), the amplitude of the AP altered independently of the hearing threshold. However, the SP remained constant throughout the fluctuation of hearing loss. This finding indicates that changes of ECoChG waveforms are associated with the presence of MD. An SP-to-AP ratio in response to a click stimulus with a value greater than 40-50% has been shown to indicate the presence of endolymphatic hydrops (Arts, Kileny, & Telian, 1997). The amplitudes of the SP and AP (measured in microvolts) have been used to determine if a person has normal hearing, sensorineural hearing loss, retrocochlear hearing loss, or MD (Hall, 2007). The ECoChG is sensitive to the presence of MD, as small changes in the endolymph fluid of the cochlea can affect the ECoChG waveforms. As shown in Figure 4, a Ménière's ear demonstrates a larger SP (whether it be positive, as in the high frequencies, or negative, as in the low frequencies) than normal ears.

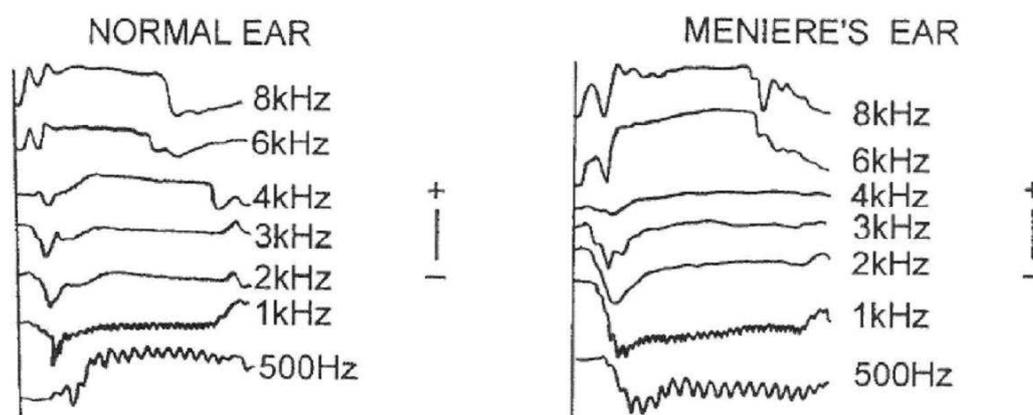


Figure 4. The SP waveforms in response to a 90 dB HL stimulus at different frequencies as measured in a normal ear (left graph) and in a Ménière's ear (right graph) (copied from Gibson, 1996; p. 14).

1.2.4 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is a neuroimaging tool used to define the nature and extent of most disease processes, including those affecting the temporal bone and other anatomical structures (Tucci & Gray, 2000). MRI images have been found to be useful for the diagnosis and treatment planning for many diseases (Tucci & Gray, 2000). Imaging of the endolymphatic space clinically has not been achieved due to differences in the chemical composition of endolymph in the inner ear (Nakashima et al., 2007). However, in recent years there has been development for an appropriate imaging method, and the use of MRI imaging for the diagnosis of MD has started to be explored in many hospitals worldwide.

Nakashima et al. (2007) reported clinical imaging of endolymphatic hydrops in nine patients using an intratympanic gadolinium injection. Each patient was injected intratympanically through the tympanic membrane with a needle and an MRI scan with a 3 Tesla unit was taken 1 or 2 hours after. In patients with MD, the perilymphatic space was found to be small, indicating the presence of a large endolymphatic space in the inner ear. Several MRI scans of endolymphatic hydrops in the vestibule and cochlea have since been reported in patients with inner ear diseases. The MRI imaging of the ear has started in recent years to be used in hospitals to standardise the evaluation of endolymphatic hydrops (Nakashima et al., 2007; Nakashima et al., 2009).

A recent study at Christchurch Hospital demonstrated imaging of endolymphatic hydrops using 1.6 ml in 10 ml saline multihance gadolinium on two patients. One patient had a “definite” MD according to the AAO-HNS CHE criteria and a positive ECochG while the other patient had “possible” MD according to the AAO-HNS CHE criteria and a negative ECochG. The patient with “definite” MD

also showed hydrops in the imaging, while the other patient did not. This showed complete diagnostic agreement with the AAO-HNS CHE standards and ECochG.

Having this technology available for future clinical diagnosis is invaluable as there is no agreement on a “gold standard” for the diagnosis of MD. However, this method of diagnosis is expensive, and still in the early stages of development. It requires not only a physician to administer the intratympanic gadolinium injection but also a radiologist to conduct an MRI imaging procedure. Most importantly, coordination is needed between the patient, otolaryngologist, and radiologist to ensure the procedure works logistically as well as being time efficient. The MRI imaging method is a time consuming test, and requires a 3 Tesla MRI scanner, which is not as affordable as other testing equipment. There is a lack of MRI studies at present in the literature, and this method needs to be tested against the current methods of diagnosis to create a gold standard if appropriate. It may be a very powerful tool and change the way MD is diagnosed in the future. Examples of the case study conducted by Dr. Jeremy Hornibrook at the Christchurch Hospital are shown in Appendix 1.

1.2.5 Treatment of MD and the Impact of Diagnosis

Sajjadi & Paparella (2008) outline several medical and surgical treatments offered to patients diagnosed with MD. Lifestyle changes such as a low salt diet, avoidance of tobacco products, caffeine, alcohol and chocolate are often the first step for many patients. Failing this, administration of diuretics or steroids in acute cases may be offered or a Meniett device or transtympanic gentamicin. Failing these treatments, surgical intervention may be necessary to relieve patients from their symptoms. Surgery options include endolymphatic sac enhancement, vestibular neurectomy or labyrinthectomy.

The impact diagnosis has on a patient can be traumatic if incorrect. Not only is the treatment for MD expensive, but it does not utilise resources effectively. Other patients may be on the waiting list longer than necessary, and it is time consuming not only for the patient but also for the health professional. If the wrong treatment is given, this may have irreversible effects on the patient, causing great trauma. It is therefore vital that any method used to diagnose MD is accurate.

It is well established that MD can be very difficult to diagnose correctly, as Thorp et al. (2003) demonstrated in a review on MD literature. Lifestyle changes may not directly harm a patient if a misdiagnosis is made; however, administration of diuretics, steroids, transtympanic gentamicin, or surgical intervention may have serious consequences for the patient if they do not have MD. Therefore it is imperative that a reliable diagnostic tool or tools is agreed on for the diagnosis of MD. This may include using the AAO-HNS CHE criteria, ECochG or a combination of both and/or with other diagnostic tools such as Gibson's score or MRI, to ensure accurate diagnosis, leading to the appropriate treatment for the patient.

Challenges with both methods in the diagnosis of MD have occurred, as the AAO-HNS CHE is subjective and does not quantify symptoms, while ECochG is invasive and requires a physician to administer the test, which may not be available in all hospitals. Treatment is administered once the physician is clinically certain the patient has MD, and will vary depending on the practice in the hospital and the experience of the attending physician. Surgery is generally considered a last option to eliminate the patient's symptoms.

If improvements on the diagnosis of MD can be made treatment can start sooner and relieve the patient of their symptoms. At the present time, the physician has to be sure that they have MD before administering any treatment, and this may

take several months. A reliable diagnosis will also save a lot of appointments and time with all involved, which is more cost effective.

1.3 Research Question

As discussed above, there are several clinical diagnostic tools for MD. This study evaluates the effectiveness of the subjective assessment methods, including AAO-HNS CHE criteria (Members of the Committee on Hearing and Equilibrium, 1995) and Gibson's score, in comparison to ECochG for detecting MD.

1.3.1 Rationale and Importance

As the AAO-HNS CHE criteria approach relies on self-report of the symptoms, the classification of the clinical diagnosis remains vague and subjective. An objective, instrumental method is needed to improve the diagnosis and management of MD. To date, ECochG has been used by some physicians and researchers to assist in the study of MD. However, the ECochG method has not been established as a common diagnostic tool mainly because there remains a lack of empirical evidence evaluating its usefulness in clinical diagnosis. Conlon and Gibson (2000) showed in a study of 2,964 ears that ECochG achieved a higher level of accuracy in detecting MD than conventional clinical examination. Empirical evidence in support of the effective usage of ECochG will lay foundations to further study for increased use of ECochG as a diagnostic tool and to enhance the management of MD.

1.3.2 Aims and Hypotheses

The purpose of this study is to gauge the inter-method reliability in the detection of MD using measures derived from subjective and instrumental methods. Specifically, the main questions are:

1. **The agreement between diagnostic tools:** How does the method of ECoChG compare to the AAO-HNS CHE criteria and Gibson's score in detecting MD?
2. **An evaluation of Electrocochleography:** What are the characteristics of the patients tested "positive" with the ECoChG measures as compared with those classified by the other two subjective measures?

Based on clinical observations and the findings reported in the literature, it was hypothesized that ECoChG would yield more defined results in the diagnosis of MD than the conventional AAO-HNS CHE criteria. The rationale for this hypothesis is that ECoChG is more defined as it objectively yields a positive or negative testing result to confirm diagnosis while the AAO-HNS CHE criteria only gives broader definitions as to whether a person has MD or not. It is hypothesized that a comparison between patients tested "positive" with the ECoChG measures and those tested "negative" would reveal differences in the relationship between various experimental measures due to different patterns of variability related to differences in the underlying pathophysiology.

Chapter Two: Methodology

2.1 Participants and Participants' Task

Medical records were retrieved to obtain data retrospectively using a quota sampling method. Subjects included a total of 250 patients (117 females and 133 males) who had been referred to the department of Otolaryngology at the Christchurch Hospital (Christchurch, New Zealand) in the period from 1994 to 2009. All subjects included had complete records of the patient's hearing test, clinical examination, evaluations performed using AAO-HNS CHE criteria, Gibson's score, and ECochG testing and results from the diagnosis of MD. The age of the patients ranged from 9 and 88 years of age (Mean = 53 years, SD = 14.42).

Before assessment by an otolaryngologist, an audiologist completed a diagnostic air conduction pure tone audiogram using the modified Hughson-Westlake procedure to detect the thresholds for 250, 500, 1,000, 2000, 4,000 and 8000 Hz for each subject bilaterally. The bone conduction threshold was obtained at the frequencies where the air conduction threshold was greater than 20 dB HL to determine whether a conductive or sensorineural hearing loss was present. The otolaryngologist took a detailed history of the patient and performed otoscopy, tuning fork tests such as the Weber and Rinne tests and a vestibular exam consisting of the Romberg test, Unterberger Stepping Test, Head-thrust test, Hallpike test, and other tests which examine cranial nerve function, cerebellum, eye movements, and the presence of nystagmus.

Patients referred for a MD examination were put on a waiting list for ECoChG testing, which was approximately two months after the initial clinical examination with the otolaryngologist. Patients were also advised to avoid excessive salt in their diet, and if appropriate, given Betahistine or other medication to help alleviate symptoms. Once a hearing test and ECoChG results were obtained, the patient was re-evaluated for any further medical intervention. The patient was then reviewed in 6 months or a year if no further problems occurred.

2.2 Instrumentation

Instruments used for the recording of ECoChG signals included an electrodiagnostic system (Amplaid MK 15, Milan, Italy), disposable electrodes (Ambu Blue Sensor electrodes, Denmark), a sterilised transtympanic needle electrode, phenol, elastic bands, and a supra-aural headphone positioned on a ring. The instrument used for data entry included laptop equipped with a relationship database program (Microsoft Access 2002). The instrumental setup is shown in Figure 5.

Calibration of the electrodiagnostic system was completed annually in August by ECS Ltd, New Zealand. The machine was connected to the patient via a series of connections. Electrodes were placed on the patient (active transtympanic needle electrode on promontory, an indifferent electrode on each earlobe, and ground electrode on the forehead). The four electrodes were then connected through wires to a biological amplifier, which was connected to the electrodiagnostic system via a long cable. From the electrodiagnostic system, the headphones were attached via a long cable to the patients head.

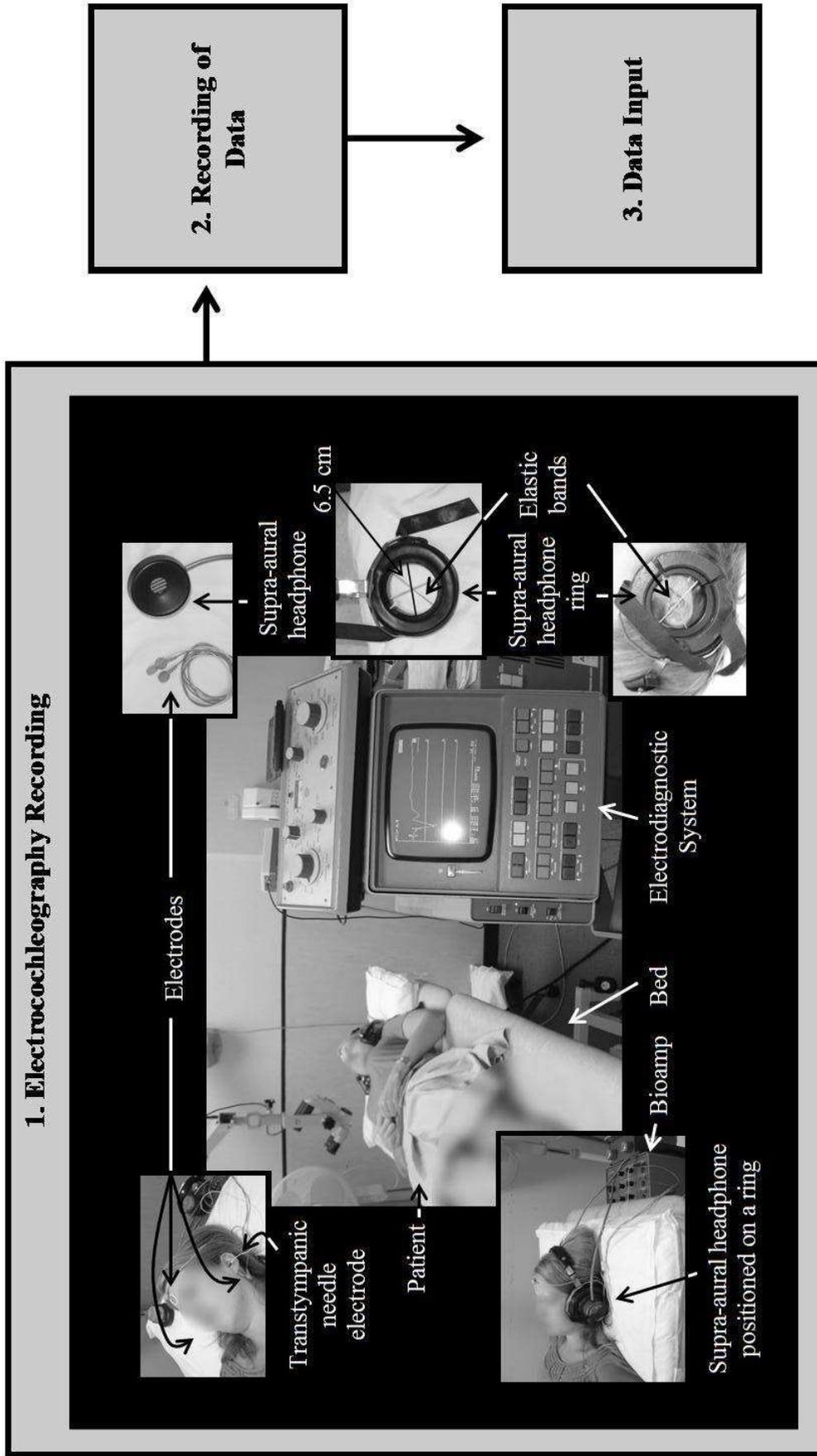


Figure 5. Instrumentation setup

2.3 Procedure

The ECoChG recording was conducted in the department of Otolaryngology at the Christchurch Hospital (Christchurch, New Zealand). The skin was prepared with Medi-Swab alcohol skin cleansing swabs (BSN Medical) and then the ground electrode was placed on the forehead and the two indifferent electrodes were placed on each earlobe. The tympanic membrane was anaesthetised with a drop of phenol before the insertion of the active electrode needle, which was a sterilised transtympanic needle electrode piercing through the tympanic membrane to rest on the promontory of the cochlea. Elastic bands attached to a ring 6.5 cm in diameter, (similar to a supra-aural headphone) were positioned over the auricle (pinna) of the test ear to secure the needle in place. The patient was instructed to lie in a supine position during testing to decrease muscle noise while the recording took place. A headphone sound source was located on the ring over the test ear and air conduction tone burst and click stimuli were used to extract an ECoChG response.

The tone burst stimuli used to elicit ECoChG AER were set at the frequency of 0.5, 1, 2, and 4 kHz respectively. The intensity of the tone bursts were 90 dBnHL for the frequencies at 500, 1,000, and 2,000 Hz, and 100 dBnHL at 4,000 Hz. The rise and fall time specified for the tone burst was 1 ms with a 14 ms plateau, with a total duration of 16 ms. The click stimuli were presented at an intensity of 90 dBnHL with a duration of 100 μ s and alternating polarity at a rate of 10 times per second. A total of 1,024 stimulus presentations per run were delivered for the tone burst stimuli and recorded, along with the response signals, with an analysis time window of 30 ms. A total of 256 stimulus presentations per run were delivered for the click stimuli and recorded, along with the response signals, with an analysis time window of 10 ms. Both the acoustic stimuli and the AER signals were filtered respectively through a

band-pass filter, which consisted a low-pass filter at 3 kHz with a 12 dB per octave filter slope and a high-pass filter at 0.5 Hz with a 6 dB per octave filter slope.

2.4 Measurements

Experimental measures in this study were derived from pure tone audiometry, Gibson's score, AAO-HNS CHE, and electrocochleography test results.

2.4.1 Pure Tone Audiometry Measurements

Data retrieved from the medical records regarding the results of the pure tone air conduction audiogram were hearing thresholds measured at five frequencies: 500, 1,000, 2,000, 4,000, and 8,000 Hz. Each patient may have more than one documented audiogram in the medical record because the patient might have had several hearing tests over the course of undergoing evaluation and treatment at the Christchurch Hospital. A mean threshold called a pure tone average (PTA) was calculated for each ear tested on the same day by averaging the thresholds measured at 500, 1,000, and 2000 Hz for each ear.

2.4.2 AAO-HNS CHE Measurements

The AAO-HNS CHE criteria as shown above in Table 3 were noted by an otolaryngologist for each patient. Any unique details of the patient's history were also noted along with the type of hearing loss and presence of vertigo attacks, tinnitus, aural fullness, disequilibrium and other causes excluded.

2.4.3 Gibson's Score Measurements

A Gibson's score was calculated by an otolaryngologist for each patient on each visit. The scoring was based on the standard point system as shown in Table 4.

2.4.4 Electrocochleography Measurements

Measurements from the ECoChG signals recorded for each patient included measures derived from signals in response to two types of acoustic stimuli, namely, tone bursts and clicks. Tone burst measurements included the summing potential amplitude (measured in μV), which were then compared against the electrocochleography norms as shown below in Table 5 (Gibson, 1994), along with action potential amplitude (in μV) and a SP-to-AP ratio, which was an amplitude ratio between the summing potential and action potential ratio. These were documented for each ear at 0.5, 1, 2, and 4 kHz. Similarly, click measurements included the summing potential amplitude (in μV), action potential amplitude (in μV), and a SP-to-AP ratio (in %).

2.5 Data Analysis

The required data was extracted from each medical record and entered into a Microsoft Access database. Data entered into the database included the patient's basic demographic information, including name, date of birth, sex, and identity number. In addition, the specific test results for auditory thresholds, Gibson's score, ECoChG measurement, and components related to the AAO-HNS CHE criteria were obtained for each patient.

The AAOHNS CHE outcome was analysed with regard to the symptoms indicated on the patient's medical records. The criteria set by the Members of the Committee on Hearing and Equilibrium (1995) as previously described were used to determine whether a patient would be classified as having "possible", "probable", "definite", or "certain" MD. Each Gibson's Score was obtained based on the scores recorded for the components included in the points system (Gibson, 2009).

Table 5. Electrocochleography norms (adapted from Gibson, 1994).

Clicks: Abnormal if SP/AP ratio ≥ 0.50

Tone Bursts:

Tone Burst Frequency	Hearing Level DBHL	Abnormal if SP \leq
500 Hz (75 DBHL)	under 25	-2 μ V
	20 - 35	-2 μ V
	40 - 55	-2 μ V
	60 - 75	-1 μ V
1 kHz (90 DBHL)	under 25	-6 μ V
	20 - 35	-6 μ V
	40 - 55	-6 μ V
	60 - 75	-3 μ V
2 kHz (100 DBHL)	under 25	-9 μ V
	20 - 35	-7 μ V
	40 - 55	-5 μ V
	60 - 75	-5 μ V
4 kHz (75 DBHL)	under 25	-9 μ V
	20 - 35	-5 μ V
	40 - 55	-5 μ V
	60 - 75	-5 μ V

2.6 Statistical Analysis

Measures yielded by the three diagnostic tools, including ECoChG, AAO-HNS CHE, and Gibson's score, were compared. Based on the ECoChG measures, patients with any recorded SP values for clicks or tone bursts greater than the normative data values, as specified in Table 5, were classified as "positive" and those with none of the recorded SP values greater than the normative data values were classified as "negative". With the ECoChG diagnostic test as the hypothetical "gold standard", the sensitivity and specificity of the two subjective tests, including AAO-HNS CHE criteria and Gibson's score, were calculated based on the formula as shown in Table 6. An ROC curve was plotted for both subjective tests to derive the proportion of patients who were correctly identified as having MD on the Y-axis against the proportion of patients who were incorrectly identified as having MD on the X-axis. The best cut-off point for each of the two ROC curves was chosen for assessment of inter-method reliability. To determine the level of agreement between the three diagnostic tools, four types of inter-method reliability, including total, point-by-point, occurrence, and non-occurrence reliability, were also calculated based on the formula as shown in Table 7. With "positive" and "negative" identifications made through the three diagnostic tools respectively, a series of chi-square tests were conducted to compare the number of patients in groups related to different classifications. A series of correlation procedures were also conducted to determine the relationships between a selection of experimental measures as a whole or in the "positive" and "negative" groups respectively. The significance level was set at 0.1, with adjustments using the Bonferroni correction in multiple testing.

Table 6. Formula for calculating the diagnostic power of the two subjective tests respectively as compared with ECoChG diagnosis.

		ECoChG diagnosis (Hypothetical “gold standard”)	
		Positive	Negative
Results from AAO-HNS CHE (or Gibson’s Score)	Positive	a (true positive)	b (false positive)
	Negative	c (false negative)	d (true negative)

$$\text{Sensitivity} = a/(a+c)$$

$$\text{Specificity} = d/(b+d)$$

$$\text{Positive predictive value} = a/(a+b)$$

$$\text{Negative predictive value} = d/(c+d)$$

Table 7. Conditions given for the calculation of four types of inter-method reliability

[formula: Reliability = (a/b) X 100].

Type of reliability	Conditions
Total reliability	a = the smaller frequency of “positive” identification by one test b = the larger frequency of “positive” identification by the other test
Point-by-point reliability	a = the number of cases with the same identification from both tests b = the total number of cases
Occurrence reliability	a = the number of cases tested “positive” in both tests b = the number of cases tested “positive” at least in one test
Non-occurrence reliability	a = the number of cases tested “negative” in both tests b = the number of cases tested “negative” at least in one test

2.7 Ethical Considerations

Ethical approval was obtained from the Upper South A Regional Ethics Committee from the New Zealand Ministry of Health, Health and Disability Ethics Committees (Ref: URA/09/06/EXP) on 4 March 2009 and the University of Canterbury Human Ethics Committee (Ref: HEC 2009/LR/10) on 2 April 2009 (Appendix 2). Patients who were tested for MD were approached by the Otolaryngologist at the time of testing and gave verbal consent to participate in MD research. Patient confidentiality was maintained in accordance with the above named ethics committees.

Chapter Three: Results

This chapter presents results from analysis of the agreement among three diagnostic tools in the detection of MD and a series of comparisons between “positive” and “negative” cases as classified with different diagnostic tools.

3.1 Agreement between Diagnostic Tools

Results on the agreement between ECochG and AAO-HNS CHE criteria, between ECochG and Gibson’s Score, and between Gibson’s score and AAO-HNS CHE criteria were reported separately as follows.

3.1.1 ROC Curves for AAO-HNS CHE Criteria and Gibson’s Score

The ROC curves for the two subjective tests as compared with the ECochG diagnosis were plotted in Figure 6, with three cut-off points (“possible”, “probable”, and “definite”) for the AAO-HNS CHE criteria and eleven cut-off points (from 0 to 10 in steps of one) for the Gibson’s score test. The area under the curve for the Gibson’s score test was significantly greater than that for the AAO-HNS CHE test (Chi-square = 22.51, $df = 1$, $p < 0.001$), indicating that Gibson’s score test was more powerful in discriminating between “positive” and “negative” ECochG cases. The ROC curve for the Gibson’s score test appears to turn at the cut-off point of seven, which falls on the cut-off value recommended by Gibson (1994) to make a positive MD diagnosis. The shape of the ROC curve for the Gibson’s score plotted with the ECochG diagnosis as the hypothetical “gold standard” is typical of a ROC curve constructed when a real “gold standard” diagnosis is available for comparison,

indicating that ECoHG testing provides a valid alternative to the two subjective methods.

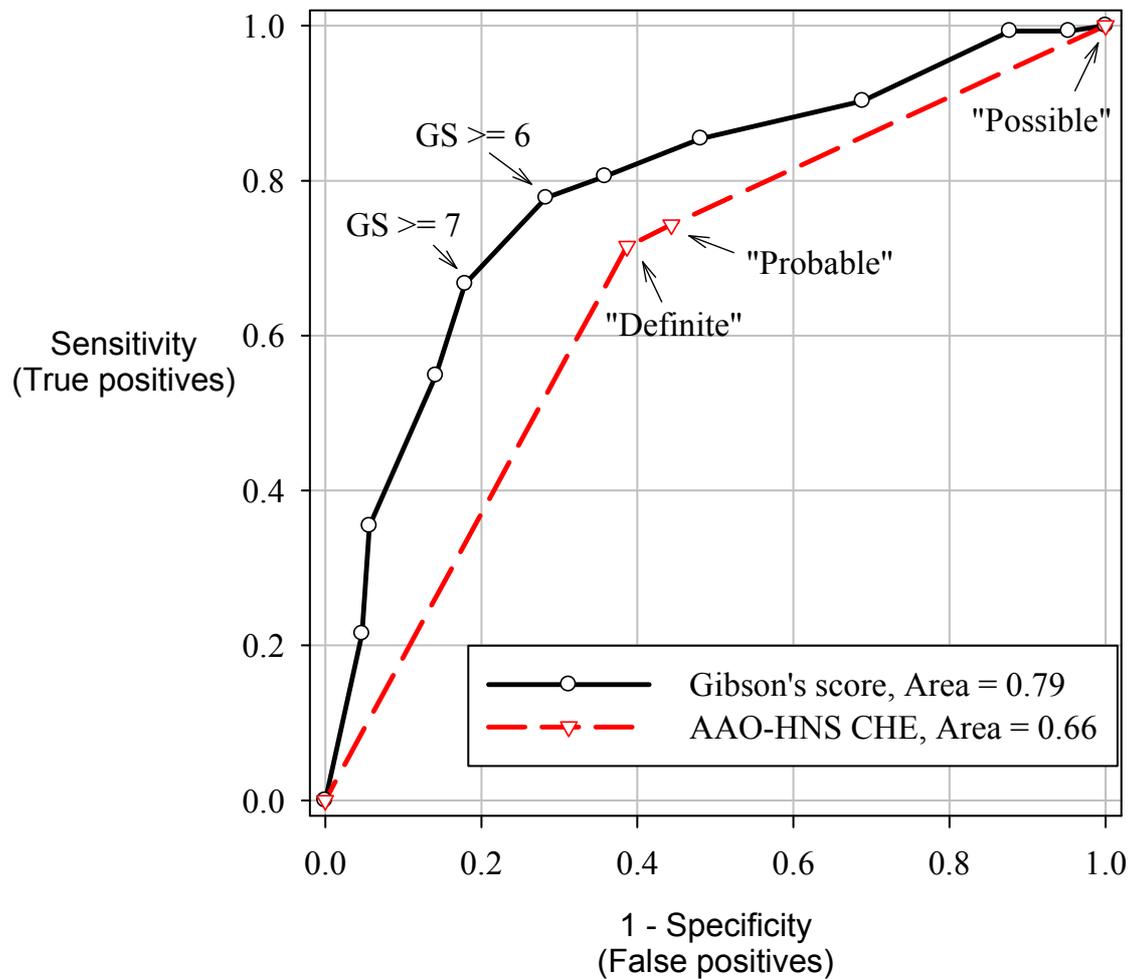


Figure 6. A receiver operating characteristic (ROC) curve showing the relationship between sensitivity and 1-specificity of the Gibson's score test at 11 cut-off points (right to left from 0 to 10) and that of the AAO-HNS CHE test at 3 cut-off points ("possible", "probable", and "definite").

Figure 7 shows the percentage of patients in the “positive” and “negative” groups as classified with different diagnostic methods. The ECochG diagnosis was based on the classification scheme as described in the previous chapter. The AAO-HNS CHE criteria were changed to a dichotomous classification in two ways. One is to group “Definite” and “Probable” as “positive” (“AAO-Definite/Probable”) and the other is to label only “Definite” as “positive” (“AAO-Definite”). The Gibson’s score with a cut-off point of 7 was used for making the diagnosis. As shown in Figure 7, both ECochG measures and AAO-HNS CHE criteria identified more positive cases (“ECochG”: 144; “AAO-Definite”: 144; “AAO-Definite/Probable”: 154; “Gibson’s Score”: 115) than negative cases while the approach with Gibson’s score identified more negative cases than positive cases.

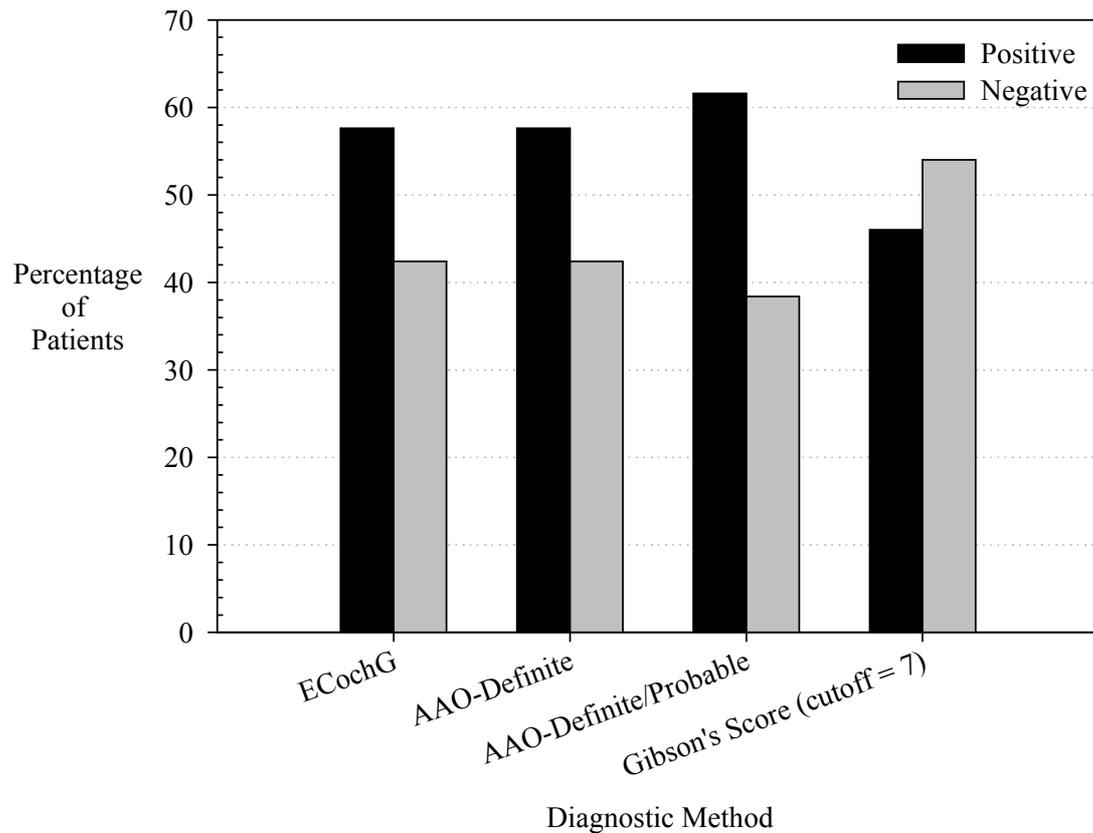


Figure 7. Percentage of patients identified as “positive” and “negative” respectively using different diagnostic methods, including ECochG, AAO-HNS CHE criteria with only “Definite” as “positive” (AAO-Definite), AAO-HNS CHE criteria with both “Definite” and “Probable” as “positive” (AAO-Definite/Probable), and Gibson’s score with the cut-off point at a value of 7.

3.1.2 Inter-method Reliability

Results of a series of inter-method reliability test conducted between ECochG and AAO-HNS CHE criteria, ECochG and Gibson’s score, and AAO-HNS CHE criteria and Gibson’s score were illustrated in Figure 8. The point-by-point, occurrence, and non-occurrence reliability were highest between the AAO-HNS CHE

criteria and Gibson's score, while the total reliability was highest between the ECoChG method and AAO-HNS CHE criteria.

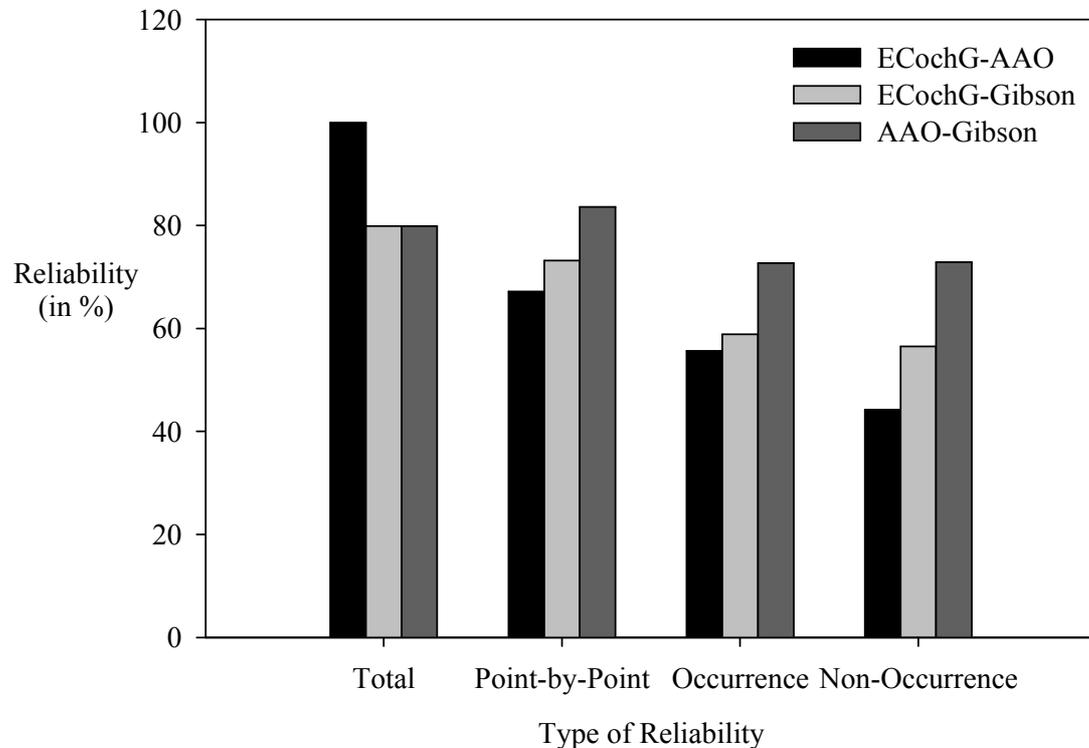


Figure 8. Total, point-by-point, occurrence and non-occurrence reliability between ECoChG measures and AAO-HNS CHE criteria, between ECoChG measures and Gibson's score, and between AAO-HNS CHE criteria and Gibson's score.

3.1.2.1 ECoChG and AAO-HNS CHE Criteria

With the "AAO-Definite" method, the degree of agreement between AAO-HNS CHE and ECoChG diagnosis was evaluated. As shown in Figure 8, the total reliability between ECoChG and AAO-HNS CHE criteria was relatively high but the point-by-point reliability was only moderately high. The occurrence reliability was slightly more than 10% higher than the non-occurrence reliability, indicating that the

inter-method agreement between ECoChG and AAO-Definite methods was higher in identifying positive cases than in identifying negative cases. Specifically, 28.4% (41/144) patients tested “positive” with the ECoChG measures were missed by the AAO-HNS CHE criteria, labelling them as only “possible” (37 patients) or “probable” (4 patients), while a higher proportion of “negative” ECoChG cases, 38.7% (41/106), was considered “positive” based on the AAO-HNS CHE criteria.

The distributions of positive and negative ECoChG cases across the three AAO-HNS CHE categories (“possible”, “probable”, and “definite”) respectively are shown in Figure 9. Both “positive” and “negative” ECoChG cases were found in all of the three AAO-HNS CHE categories of diagnosis. However, as shown in Figure 9, a general agreement existed between the two diagnostic tests, with a relatively high proportion (over 70%) of “positive” ECoChG cases found in the “definite” category and a moderately high proportion (over 50%) of “negative” ECoChG cases found in the “possible” category.

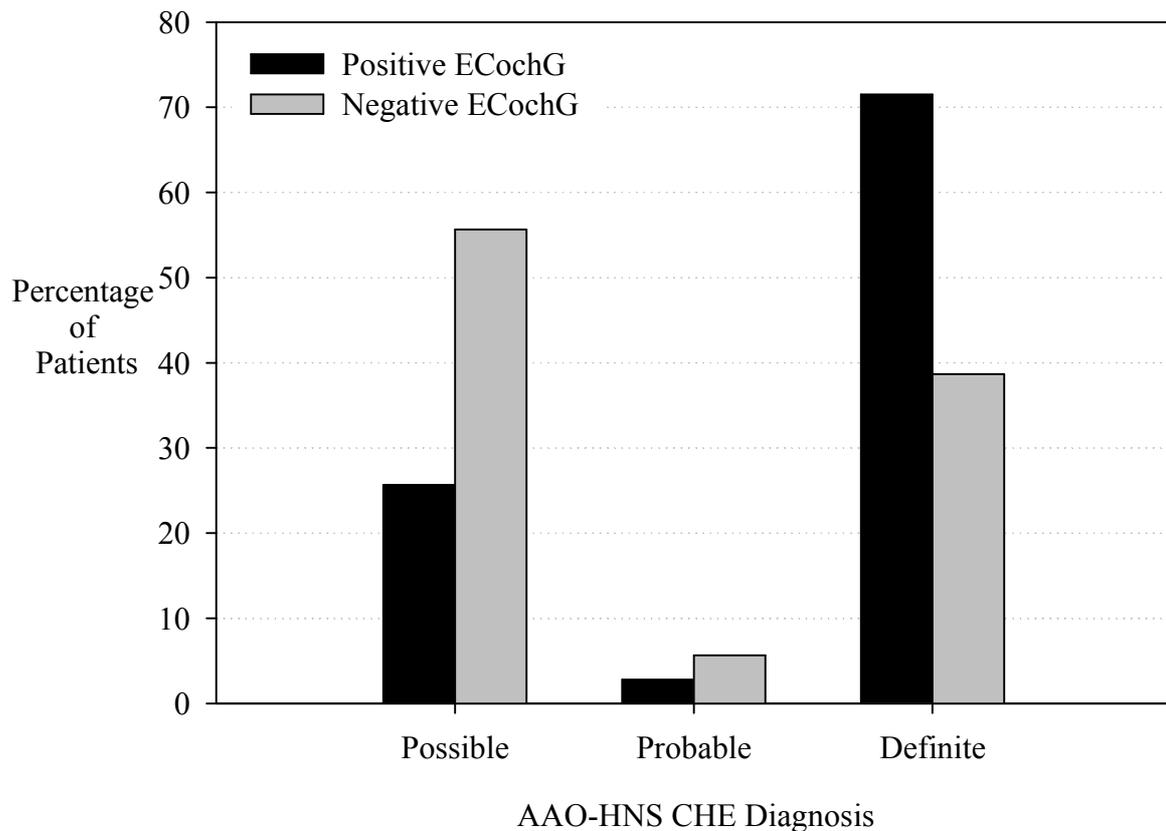


Figure 9. The respective distribution of “positive” and “negative” ECoChG cases across the three categories of AAO-HNS CHE criteria.

3.1.2.2 *ECoChG and Gibson’s Score*

According to the Gibson’s scale, a patient was considered “positive” for the diagnosis of MD when achieving a Gibson’s score of seven or greater and “negative” if less than seven. As shown in Figure 8, the total and point-by-point reliability between ECoChG and Gibson’s score was both high, with the occurrence reliability only very slightly better than the non-occurrence reliability. The distributions of positive and negative ECoChG cases across the eleven levels of Gibson’s score

respectively are shown in Figure 10. It can be observed from Figure 10 that the distribution of “negative” ECoChG cases (frequency shown as grey bars) gravitated to the lower end of the Gibson scale and the distribution of the “positive” ECoChG cases (black bars) gravitated to the higher end of the scale. Specifically, a higher proportion of positive ECoChG cases were found in a Gibson’s score around 6 and 7 and above. A higher proportion of negative ECoChG cases were associated with a Gibson’s score below 6, with a dramatic decrease of negative ECoChG cases at a Gibson’s score of 7.

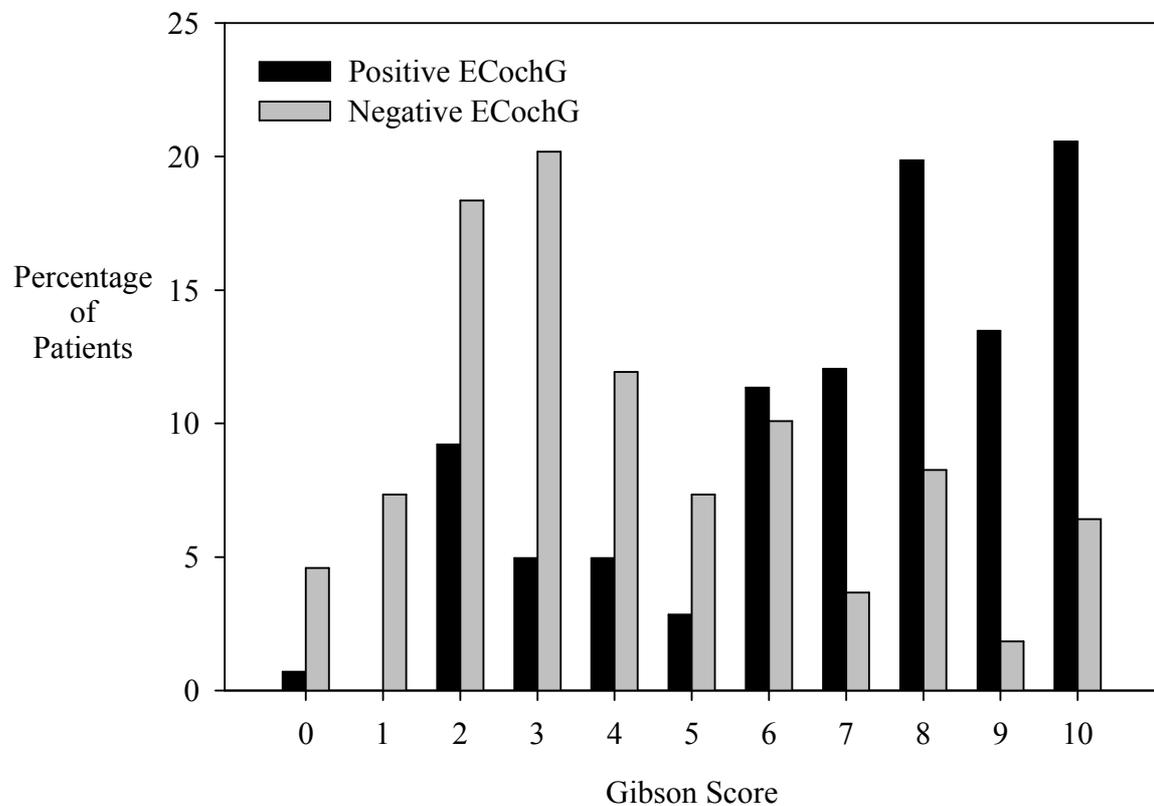


Figure 10. The respective distribution of “positive” and “negative” ECoChG cases across different levels of Gibson’s score.

3.1.2.3 Gibson's Score and AAO-HNS CHE Criteria

With the cut-off points for MD diagnosis with both Gibson's score and AAO-HNS CHE as previously described, Gibson's score and AAO-HNS CHE generally showed a relatively high inter-method reliability (see Figure 8). The distributions of positive and negative AAO-HNS cases across the eleven levels of Gibson's score respectively are shown in Figure 11. In a similar manner as previously described regarding the cross-over of the distributions of "positive" and "negative" ECoHG cases on the Gibson's scale, the direction of the frequency difference between Gibson's score and AAO-HNS CHE test was reversed around a Gibson's score of 7.

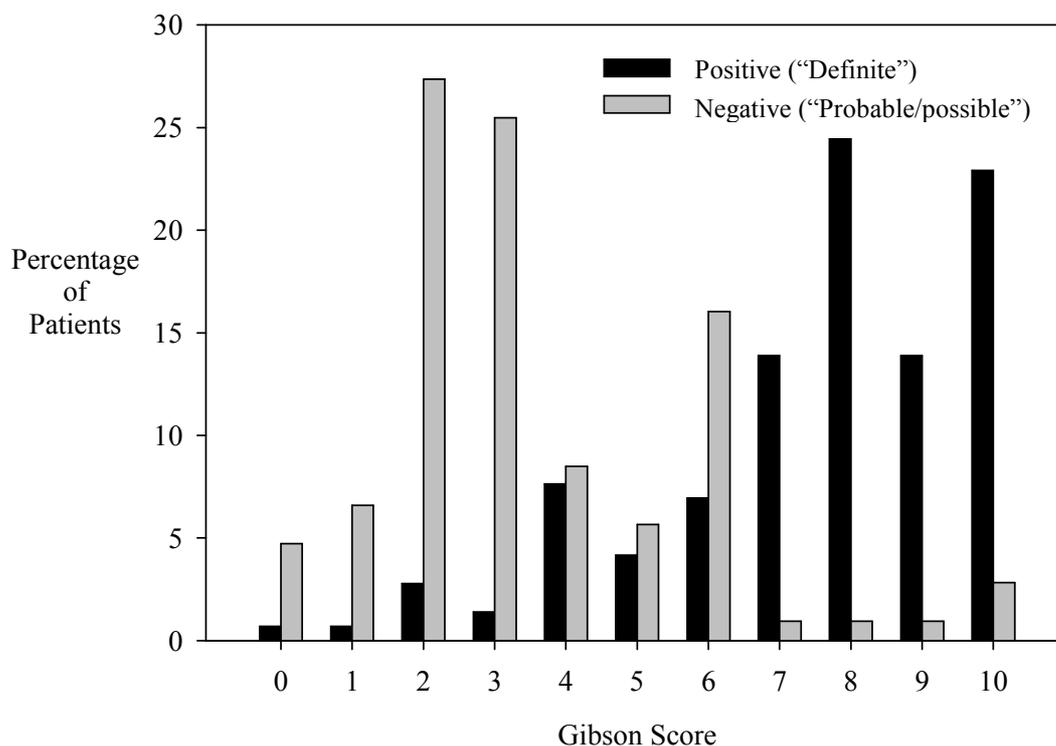


Figure 11. The respective distribution of "positive" and "negative" AAO-HNS CHE cases across different levels of Gibson's score.

3.1.2.4 Tone-burst and Click ECoChG

A comparison of tone-burst and click ECoChG results for the total number of patients diagnosed with a positive ECoChG is shown in Figure 12. There were numerous positive tone-burst ECoChG results compared to positive click ECoChG results. In particular, the 1 and 2 kHz tone-burst ECoChG measures yielded more positive outcomes than 500 Hz and 4 kHz. Table 8 shows the correlations between the SP/AP ratios obtained from click ECoChG and tone-burst ECoChG at 0.5, 1, 2, and 4 kHz from the same ear. As shown in Table 8, these correlations were generally low except for the correlation between click and the tone-burst ECoChG at 2 kHz, where the a stronger correlation was found in “positive” group than in the “negative” group.

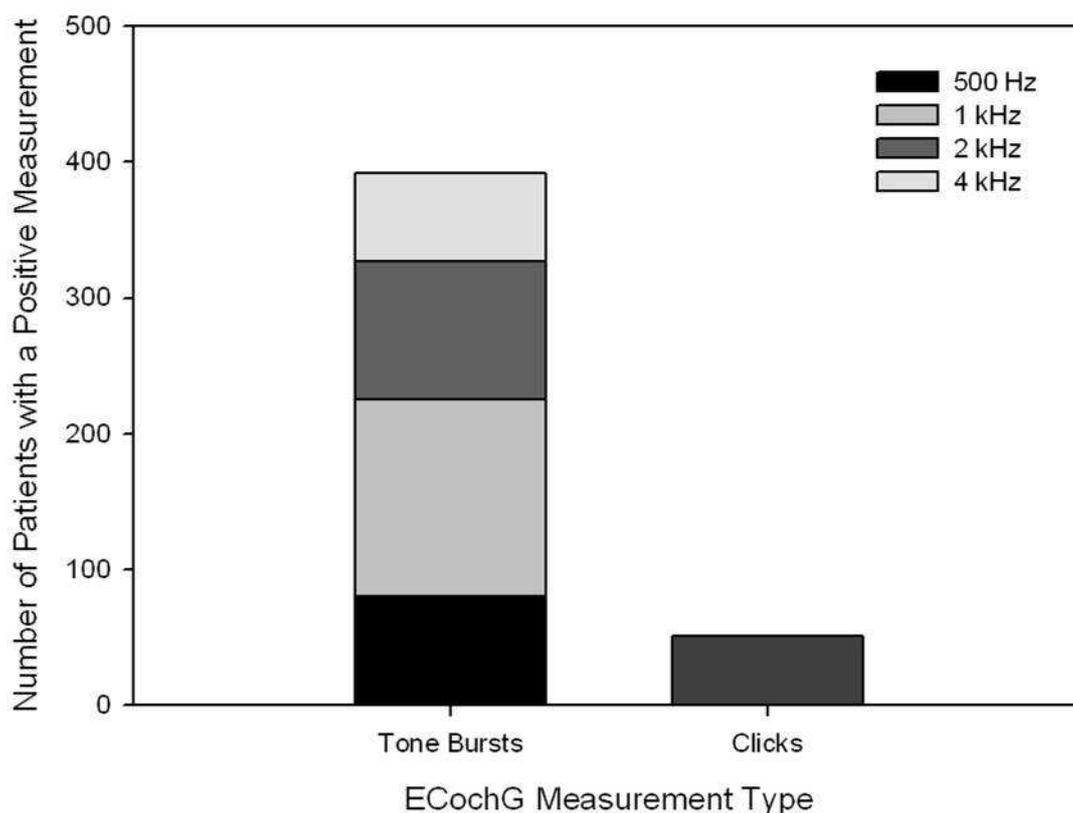


Figure 12. Number of “positive” tone burst and click ECoChG results.

Table 8. Correlations (Pearson’s r) between SP/AP ratios obtained from click ECoChG and those from tone-burst ECoChG at 500, 1,000, 2000, and 4,000 Hz in the “positive” (POS) and “negative” (NEG) cases classified by three diagnostic methods.

		EcochG		AAO-Definite		Gibson	
		POS	NEG	POS	NEG	POS	NEG
500 Hz	R	0.17	0.01	0.23	0.07	0.23	0.08
	L	0.08	-0.02	0.22	0.01	0.14	0.16
1,000 Hz	R	0.39	0.20	0.45	0.38	0.47	0.35
	L	0.35	0.19	0.45	0.35	0.41	0.39
2000 Hz	R	0.47	0.23	0.55*	0.35	0.57*	0.34
	L	0.36	-0.03	0.47	0.21	0.47	0.23
4,000 Hz	R	0.27	0.21	0.39	0.18	0.31	0.29
	L	0.12	0.08	0.21	0.13	0.19	0.15

* Significant correlations with a coefficient above 0.5 are in boldface.

3.2 Comparisons between “Positive” and “Negative” ECoChG Cases

Results from an analysis of the distributions of “positive” and “negative” ECoChG cases across symptoms, types of hearing loss, and various classifications were shown as follows.

3.2.1 Relationships between Symptoms of MD

Figure 13 shows the percentage of patients exhibiting each of the four key MD symptoms, including hearing loss, vertigo, tinnitus, and feeling of aural fullness. In general, there were a higher proportion of patients exhibiting each of these symptoms in the group tested “positive” with ECoChG measures than the “negative” group. Both hearing loss and vertigo were highly prevalent in the patients included in this study regardless of ECoChG diagnosis. As shown in Figure 13, for patients that tested “positive” with ECoChG measures, hearing loss was the most prevalent symptom, followed in order by vertigo, tinnitus, and feeling of aural fullness. For patients tested “negative” with ECoChG measures, vertigo was the most prevalent symptom, followed in order by hearing loss, tinnitus, and feeling of aural fullness. With the significance level adjusted from 0.1 to 0.016 for multiple testing, no significant difference on the occurrence rate was found between hearing loss and vertigo (“positive” ECoChG: Chi-square = 0.098, df = 1, p = 0.75; “negative” ECoChG: Chi-square = 0.615, df = 1, p = 0.43). A significant difference on occurrence rate was found for all the other pair-wise comparisons, including those between hearing loss and tinnitus (“positive” ECoChG: Chi-square = 44.5, df = 1, p < 0.001; “negative” ECoChG: Chi-square = 8.621, df = 1, p = 0.003), hearing loss and aural fullness (“positive” ECoChG: Chi-square = 74.37, df = 1, p < 0.001 ; “negative” ECoChG: Chi-square = 51.65, df = 1, p < 0.001), vertigo and tinnitus (“positive” ECoChG: Chi-square = 7.645, df = 1, p = 0.006; “negative” ECoChG: Chi-square = 14.73, df = 1, p < 0.001), vertigo and feeling of aural pressure (“positive” ECoChG: Chi-square = 23.69, df = 1, p < 0.001 ; “negative” ECoChG: Chi-square = 63.88, df = 1, p < 0.001), and tinnitus and feeling of aural pressure (“positive” ECoChG: Chi-square = 6.07, df = 1, p = 0.014; “negative” ECoChG: Chi-square = 18.79, df = 1, p < 0.001).

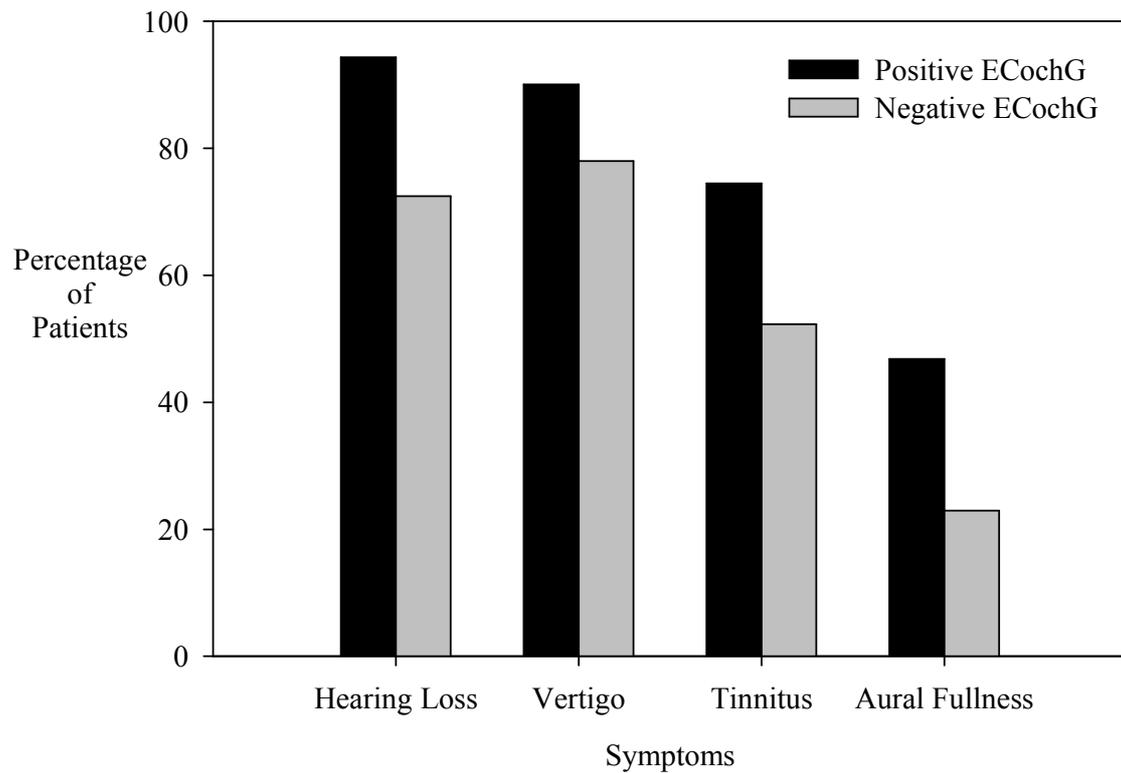


Figure 13. Percentage of patients showing each of the four key symptoms of MD.

Table 9 provides a summary of the results from a series of Spearman’s rho correlation procedures conducted between the Gibson’s sub-scores for the four key symptoms of MD, including hearing loss, vertigo, tinnitus, and feeling of aural fullness. Regardless of the method used for MD diagnosis, “positive” diagnosis was generally associated with a high correlation among the four key symptoms while “negative” diagnosis showed relatively marginal or no significant correlations between symptoms.

Table 9. Correlations (Spearman rho) between the four key symptoms in the “positive” (POS) and “negative” (NEG) cases classified by three diagnostic methods.

		Hearing Loss		Vertigo		Tinnitus	
		POS	NEG	POS	NEG	POS	NEG
<i>ECochG:</i>							
Vertigo	R	0.77*	0.21				
	L	0.79*	0.17				
Tinnitus	R	0.67*	0.18	0.57*	0.44		
	L	0.71*	0.33	0.70*	0.33		
Aural fullness	R	0.53*	0.42	0.51*	0.46	0.58*	0.44
	L	0.59*	0.02	0.53*	0.17	0.57*	0.20
<i>AAO-HNS CHE (“Definite” as positive):</i>							
Vertigo	R	0.80	0.17				
	L	0.80	0.16				
Tinnitus	R	0.66	0.18	0.75*	-0.07		
	L	0.70	0.17	0.73*	0.005		
Aural fullness	R	0.58	0.28	0.64*	-0.01	0.52*	0.45
	L	0.53	0.17	0.56*	0.03	0.44	0.41
<i>Gibson’s Score (cut-off point at 7):</i>							
Vertigo	R	0.92*	0.08				
	L	0.89*	0.21				
Tinnitus	R	0.73*	0.05	0.81*	-0.06		
	L	0.80*	0.23	0.87*	0.19		
Aural fullness	R	0.57*	0.22	0.61*	0.03	0.50*	0.40
	L	0.61*	0.01	0.67*	-0.02	0.62*	0.08

* Significant correlations with a coefficient above 0.5 are in boldface.

3.2.2 Hearing Loss Patterns

Results of an analysis of the distributions of “positive” and “negative” ECoChG cases across different levels of hearing loss are illustrated in Figure 14. It could be observed from Figure 14 that the mode of the “negative” ECoChG cases tended to lean toward the end of normal hearing while the “positive” ECoChG cases mostly presented with a mild to moderate-to-severe hearing loss. Figure 15 illustrates the between-ear contrast on hearing threshold. There were generally a higher proportion of asymmetrical hearing thresholds, with similar occurrence rate for the left or right ear to be the poorer ear. However, the “positive” ECoChG group was found to have a significantly higher proportion of patients showing asymmetrical hearing thresholds than the “negative” ECoChG group (Chi-square = 9.66, $df = 1$, $p = 0.002$). In addition, the occurrence rate across the three types of between-ear contrast was found to be significantly different in the “positive” ECoChG group (Chi-square = 46.15, $df = 2$, $p < 0.001$) but not in the “negative” ECoChG group (Chi-square = 2.51, $df = 2$, $p = 0.286$). As shown in Figure 15, the occurrence rates for the left or right ear to be the poorer ear were not significantly different (Chi-square = 0.058, $df = 1$, $p = 0.811$) but there was, in the “positive” ECoChG group, a significantly lower occurrence rate of symmetrical threshold as compared with asymmetrical threshold shift, whether the poorer threshold was found in the left ear (Chi-square = 34.59, $df = 1$, $p < 0.001$) or right ear (Chi-square = 38.548, $df = 1$, $p < 0.001$).

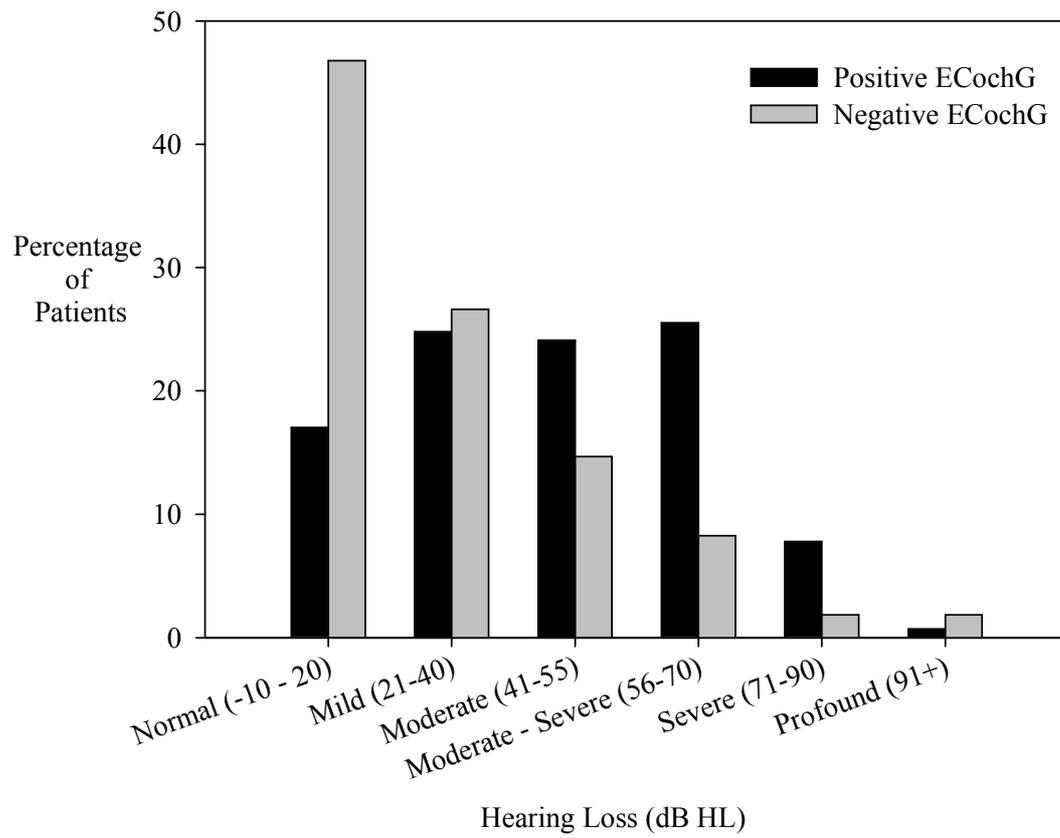


Figure 14. The respective distribution of “positive” and “negative” ECoChG cases across different levels of hearing loss.

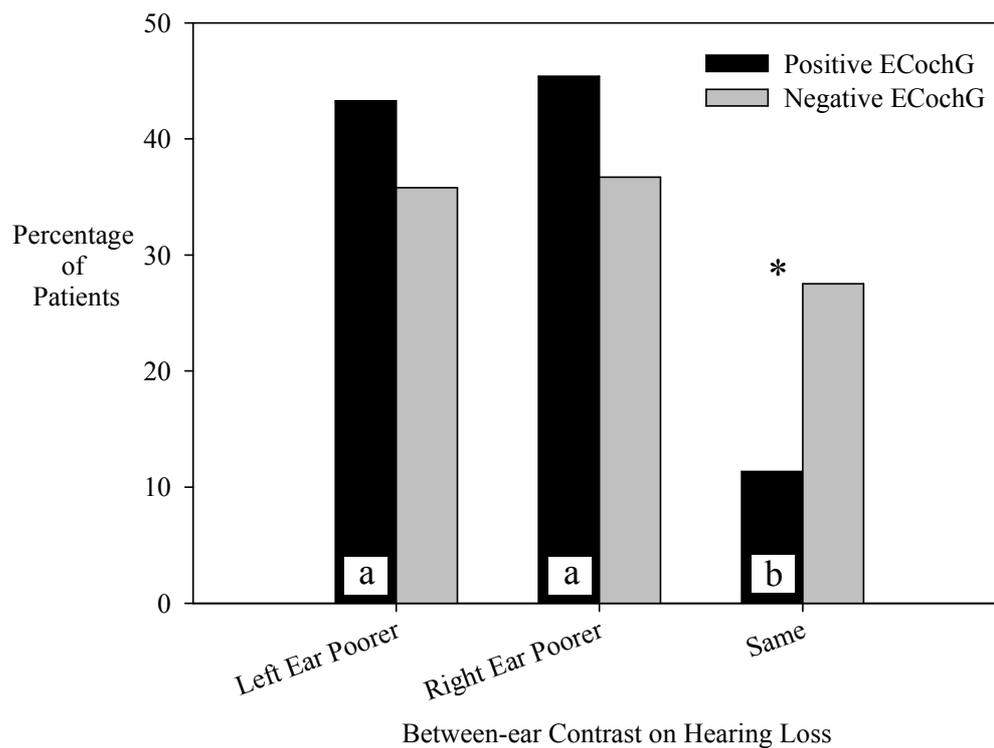


Figure 15. The respective distribution of “positive” and “negative” ECoChG cases across three types of between-ear contrast on hearing loss. Significantly different between-type comparisons were marked with different letters. Significantly different between-diagnosis comparisons were marked with an asterisk (“*”).

As for the level of between-ear threshold difference, Figure 16 illustrates a comparison between the “positive” and “negative” ECoChG groups on the proportions of patients with low (0-15 dB HL) and high (equal or greater than 20 dB HL) between-ear threshold differences. As shown in Figure 16, a significantly higher proportion of “positive” cases exhibited greater between-ear threshold difference (Chi-square = 11.12, df = 1, $p < 0.001$) while a significantly higher proportion of

“negative” cases showed lower between-ear threshold difference (Chi-square = 84.84, $df = 1$, $p < 0.001$).

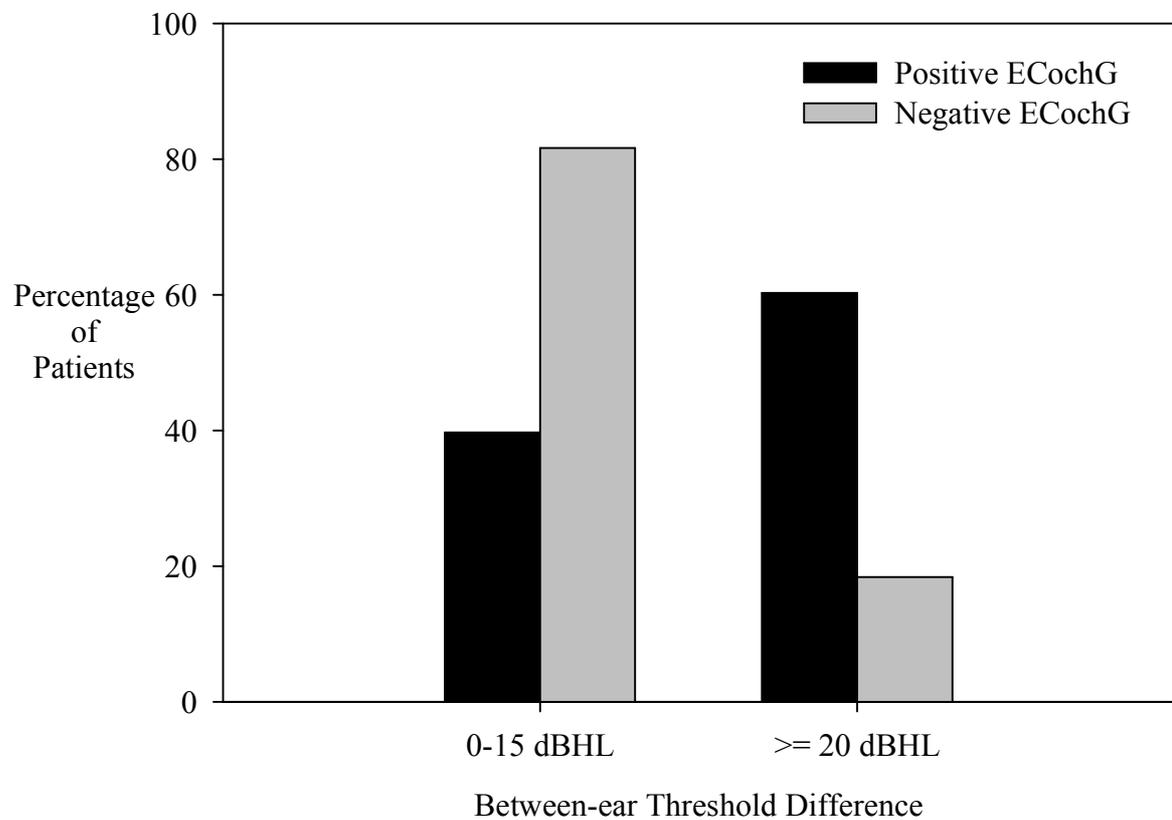


Figure 16. The respective distribution of “positive” and “negative” ECoChG cases across two different levels of between-ear threshold differences.

Figure 17 shows the average hearing thresholds at 0.5, 1, 2, and 4 kHz for the “positive” and “negative” ECoChG groups respectively. It can be observed from Figure 17 that the “negative” ECoChG groups have a lower average hearing threshold at all frequencies than the “positive” ECoChG groups. The highest hearing threshold is at 4 kHz for both “positive” and “negative” ECoChG groups.

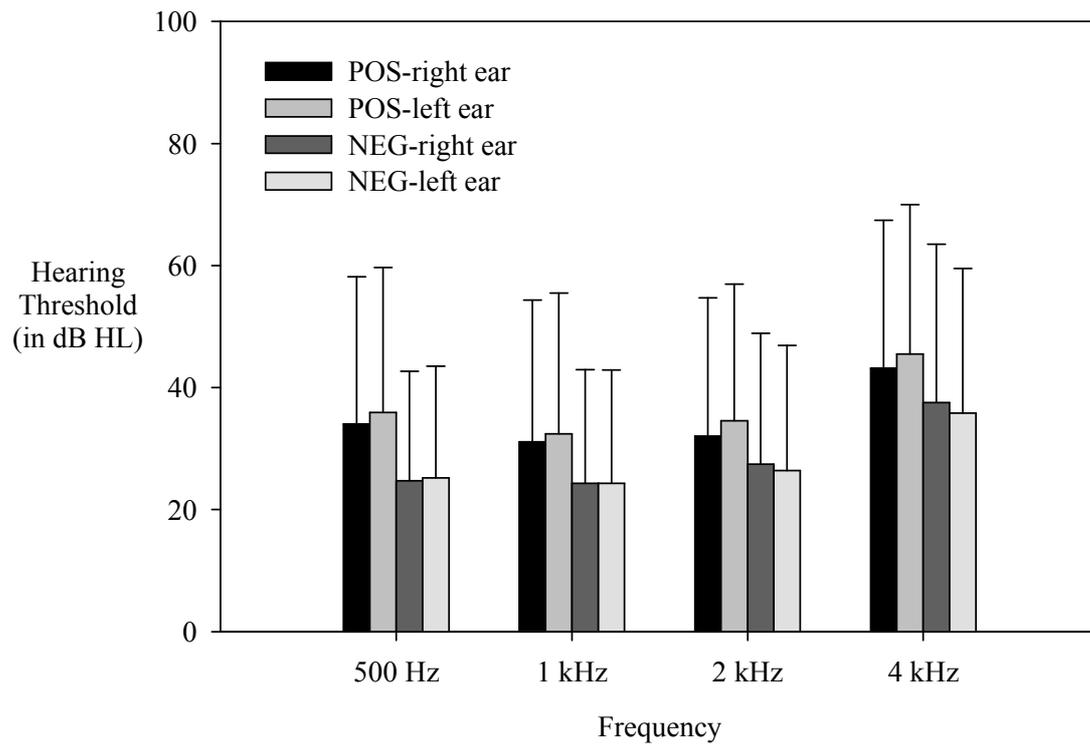


Figure 17. Means and standard deviations of the hearing thresholds as measured at 0.5, 1, 2, and 4 kHz frequencies for the “positive” and “negative” ECoChG groups.

3.2.3 Relationships between ECochG Measures

Table 10 shows the results from a series of Pearson's Product Moment correlation procedures conducted to determine the relationships between the SP/AP ratios obtained at 0.5, 1, 2, and 4 kHz respectively in the "positive" and "negative" groups as classified by the three diagnostic tools respectively. As shown in Table 10, the SP/AP ratios measured at adjacent frequencies (i.e., 0.5 and 1 kHz, 1 and 2 kHz, and 2 and 4 kHz) were positively and moderately or highly correlated in the "positive" group regardless of the type of diagnostic tool used. This correlation may or may not be maintained in the "negative" group, especially for the correlation between the 2 and 4 kHz in the "negative" ECochG group.

Table 10. Correlations (Pearson's r) between SP/AP ratios obtained at 0.5, 1, 2, and 4 kHz in the "positive" (POS) and "negative" (NEG) cases classified by three diagnostic methods.

		500 Hz		1,000 Hz		2000 Hz	
		POS	NEG	POS	NEG	POS	NEG
<i>ECoG:</i>							
1,000 Hz	R	0.49	0.20				
	L	0.52	0.44				
2000 Hz	R	0.37	0.22	0.70	0.63		
	L	0.37	0.38	0.72	0.47		
4,000 Hz	R	0.26	0.19	0.42	0.21	0.48	0.31
	L	0.22	0.23	0.35	0.51	0.53	0.34
<i>AAO-HNS CHE ("Possible" as negative):</i>							
1,000 Hz	R	0.50	0.43				
	L	0.61	0.50				
2000 Hz	R	0.42	0.36	0.74	0.75		
	L	0.45	0.51	0.71	0.69		
4,000 Hz	R	0.39	0.17	0.43	0.48	0.46	0.57
	L	0.21	0.41	0.29	0.65	0.52	0.47
<i>Gibson's Score (cut-off point at 7):</i>							
1,000 Hz	R	0.51	0.41				
	L	0.60	0.51				
2000 Hz	R	0.46	0.31	0.78	0.70		
	L	0.41	0.50	0.70	0.69		
4,000 Hz	R	0.42	0.16	0.43	0.46	0.47	0.54
	L	0.17	0.43	0.22	0.64	0.44	0.55

* Significant correlations with a coefficient above 0.5 were in boldface.

The finding of a higher correlation between ECoChG measures in the “positive” group than the “negative” group suggested that the consistency of SP/AP ratios across frequencies may be a sign of MD. Therefore, the coefficient of variation (COV) of the mean and standard deviation of the SP/AP ratios extracted from the four frequencies was obtained for each ear. The COV was defined as 100 times the ratio of standard deviation to mean. The value from the ear with a higher COV was selected for each patient for statistical analysis. Figure 18 shows the means and standard deviations of the COV in the “positive” and “negative” groups as classified by the three diagnostic methods (ECoChG, AAO-Definite, Gibson’s Score with the cut-off point at 7). The six sets (2 diagnostic groups X 3 diagnostic methods) of COV values were submitted to a two-way Analysis of Variance. Results revealed no significant method effect [$F(2, 76) = 0.236, p = 0.79$] but a significant diagnostic group effect [$F(1, 726) = 26.244, p < 0.001$] and method by group interaction effect [$F(2, 726) = 5.063, p = 0.007$]. As shown in Figure 18, the “positive” group had a higher mean COV than the “negative” group regardless of the method used for the classification. Post-hoc testing revealed that the COV in the “positive” group was significantly higher than that in the “negative” groups only when the classification was based on ECoChG measures. As eleven patients in this sample had ECoChG recordings at other times, the change of COV over time for patients with repeated ECoChG recordings at different points of time was shown in Appendix 3. For these patients, the ECoChG measures recorded at the last day on the record had been selected for use in all analysis in the previous section.

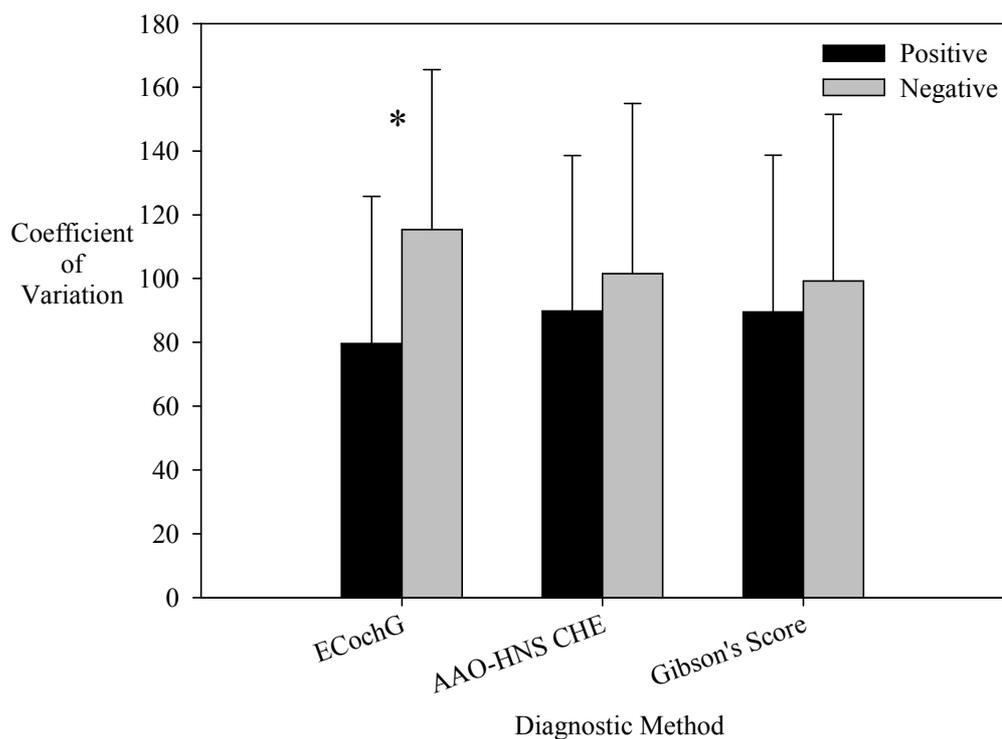


Figure 18. Means and standard deviations of the coefficient of variation (for tone burst ECochG across frequencies) obtained from the “positive” and “negative” patients as classified by three diagnostic methods, including ECochG, AAO-HNS CHE criteria with only “Definite” as “positive”, and Gibson’s score with the cut-off point at a value of 7.

3.2.4 Demographic Information

An analysis of the demographic data revealed that more males were diagnosed with MD than females in this study (see Figure 19). The majority of the subjects in this particular sample were European, with only a few patients from other ethnic groups (See Figure 20). The majority of the patients (87.24%) who tested “positive”

for MD with ECoChG measures were between the ages of 41 and 80 years of age (see Figure 21). It was shown in Figure 22 that more “positive” ECoChG cases had unilateral rather than bilateral MD. Furthermore, more bilateral MD cases were identified using the ECoChG method as compared with the Gibson’s score (See Figure 23). Figure 24 showed the total number of ears tested as shown in the Gibson scale from the AAO-HNS CHE diagnosis. It could be observed that a “positive” AAO-HNS CHE criteria diagnosis can be made throughout Gibson’s scale, not just above the cut-off score of 7. This occurs in particular, at the Gibson score of 2 and 3.

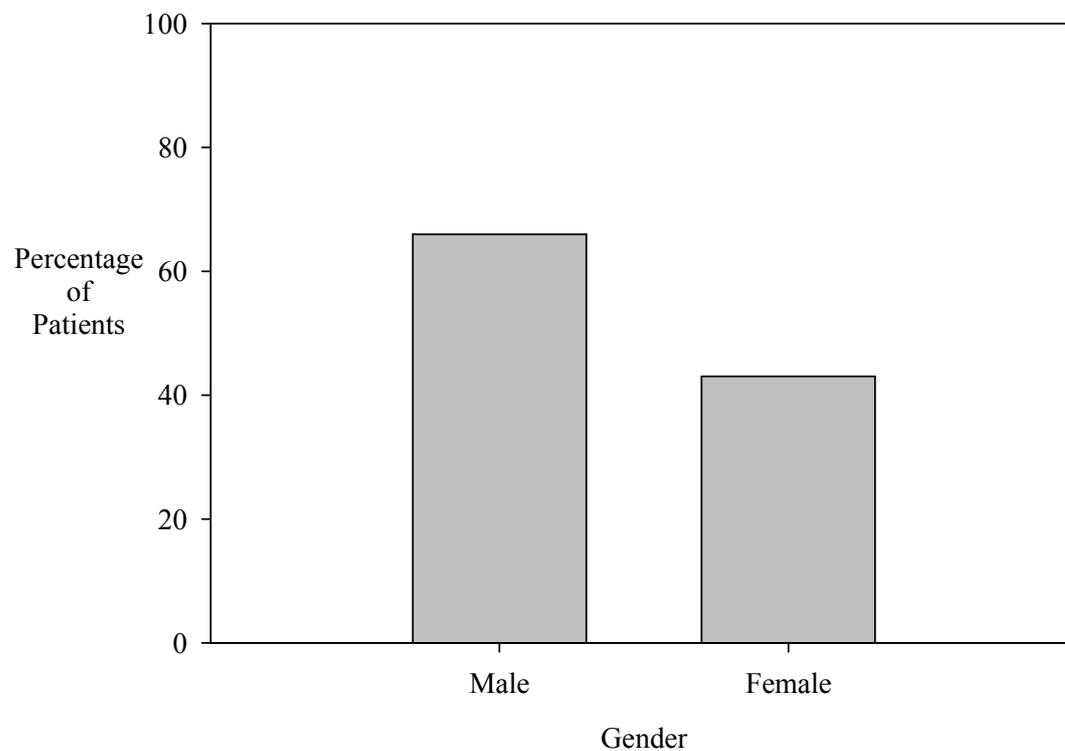


Figure 19. Percentage of “positive” ECoChG cases in each gender.

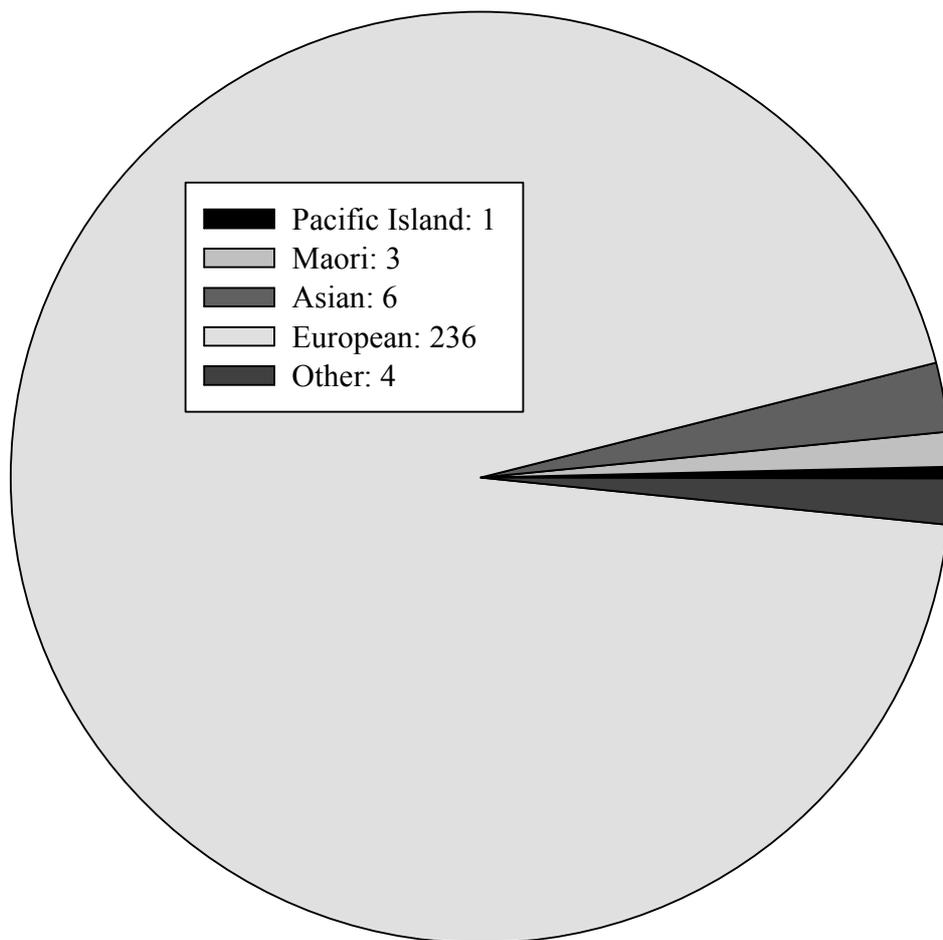


Figure 20. Ethnicity of all the 250 patients included in this study.

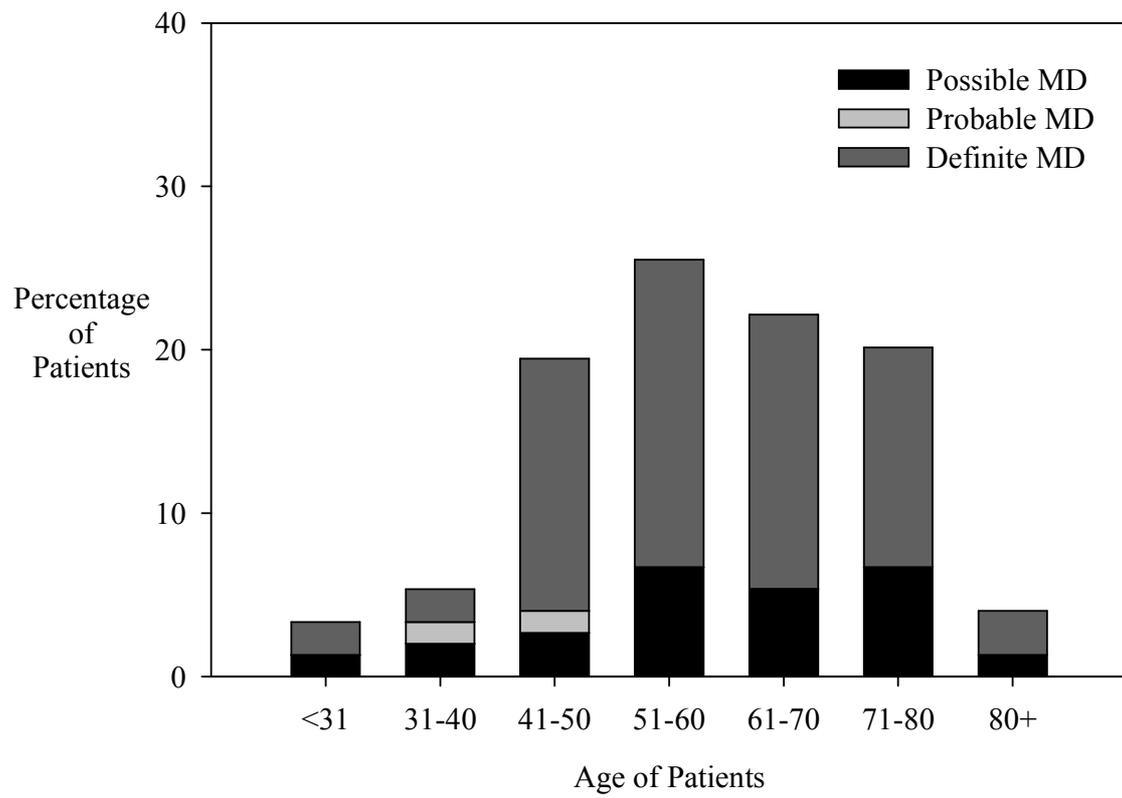


Figure 21. Percentage of “positive” ECoG cases in each age range as compared to the AAO-HNS CHE diagnosis.

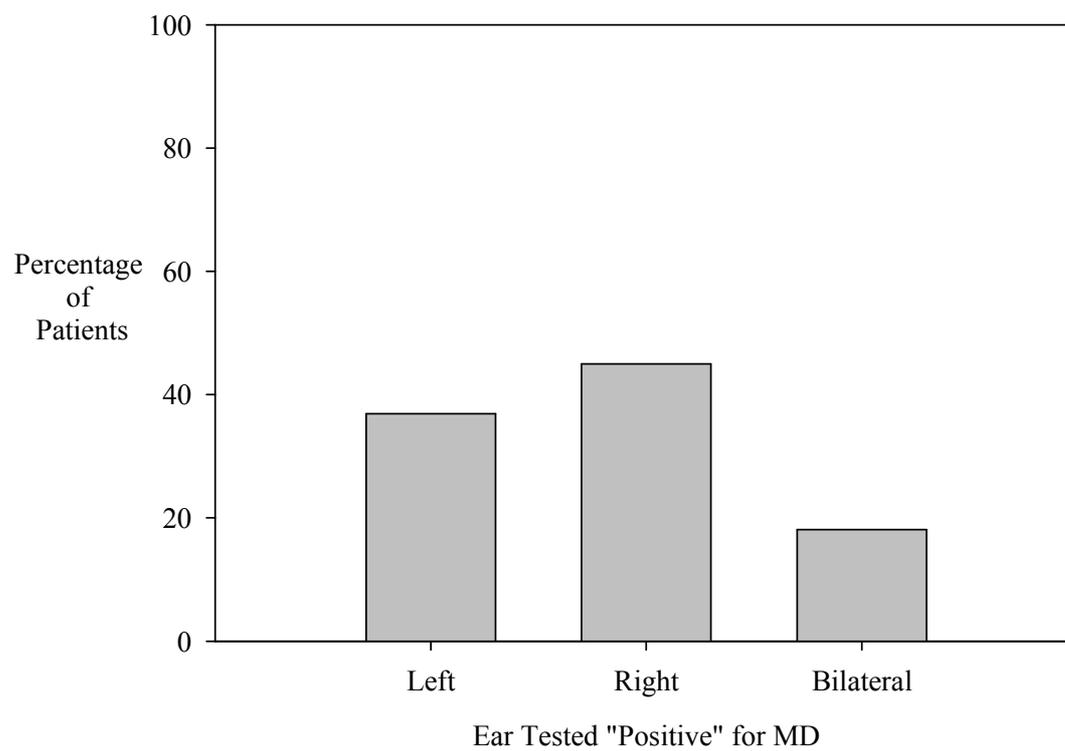


Figure 22. Percentage of “positive” ECoChG cases presenting with a unilateral left or right ear or bilateral sign of MD.

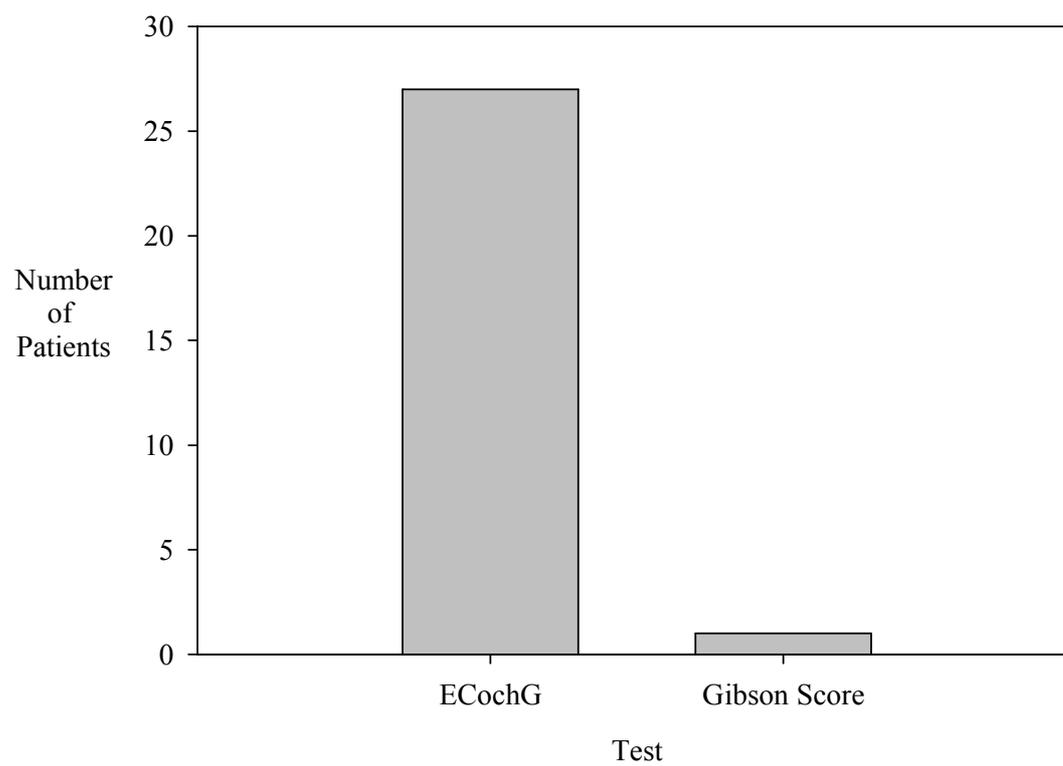


Figure 23. The number of patients identified as having bilateral Ménière's disease.

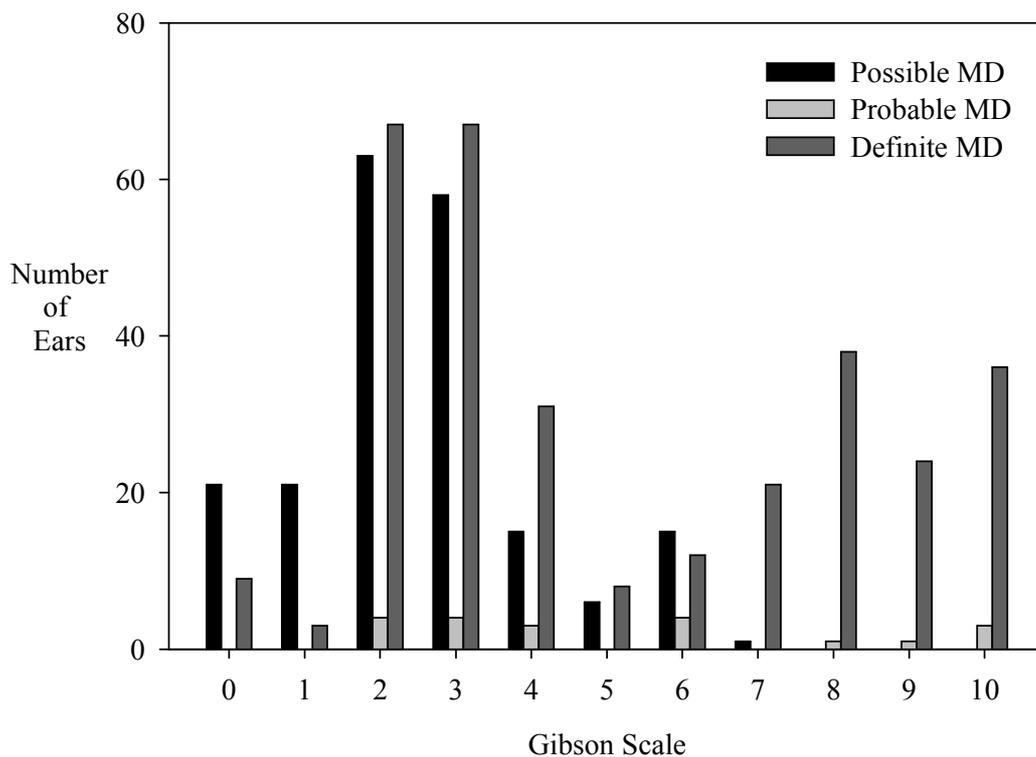


Figure 24. Total number of ears tested as shown in the Gibson scale from the AAO-HNS CHE diagnosis.

3.3 Summary of Main Findings

The ROC curves showing the relationship between the two subjective assessment tools when compared against the ECoChG diagnosis had a shape characteristic of an ROC curve generated with a “gold standard” for comparison. The agreement between the three tests was generally high, with a few disagreements on individual diagnoses. The ECoChG method was found to identify more patients with bilateral MD than the Gibson’s score. Patients who tested “positive”, regardless of the diagnostic methods, tended to show a higher correlation among the four key symptoms of MD. There was also a higher correlation between ECoChG measures at

adjacent frequencies and a lower variation of SP/AP ratios across frequencies in the “positive” group as compared with the “negative” group.

Chapter Four: Discussion

The purpose of this study was to evaluate how ECoChG may function as a diagnostic tool for MD as compared with the conventional clinical tests. Findings from the present study revealed that the subjective and objective assessment generally were in agreement, with a few disagreements on individual diagnoses. The ECoChG method was in better agreement with Gibson's score than the AAO-HNS CHE criteria. This findings in this study also suggested that a diagnosis of MD should not be made with a single diagnostic tool in their present form of application. In addition, there was some evidence suggesting that the signs of MD may be distinguishable from those of other causes based on the consistency between ECoChG measures obtained at adjacent frequencies.

4.1 The Agreement between Diagnostic Tools

Electrocochleography has been documented in the literature for over 30 years as a tool for the diagnosis, assessment, and monitoring of patients with MD (Almomani, Ferraro, Gajewski & Ator, 2009). The AAO-HNS CHE criteria has been used as a formalised diagnostic tool from 1972 and since then, has undergone revisions in 1985 and 1995 (Committee on Hearing and Equilibrium, 1972; Committee on Hearing and Equilibrium, 1985; Members of the Committee on Hearing and Equilibrium, 1995). Both of these diagnostic evaluation tools for MD have been clinically used for several years. When compared to each other as diagnostic tools, some level of disagreement in diagnosis was found where the patient tested "negative" were labelled "definite MD" in AAO-HNS CHE diagnosis or the

patient tested “positive” with ECoChG measures was given a diagnosis of “negative” based on the AAO-HNS CHE criteria. Using the classification scheme as defined in this study, the total between-test agreement was high, but only moderate in the point-by-point reliability. A proportion of patients were diagnosed differently by the three different diagnostic tools. However, the true diagnosis of this group of patients, as well as all patients of the like, is not available unless a post-mortem takes place after the death of the patient.

There are several differences when using either ECoChG or AAO-HNS CHE criteria as diagnostic tools for the diagnosis of MD. The ECoChG has been considered a specific tool rather than a sensitive tool when using for a diagnosis of MD. As reported by Al-momani et al. (2009), previous literature has shown ECoChG to be specific to the disorder but not adequately sensitive for evaluating possible MD in a patient (with sensitivity estimated around 20-65%). In an attempt to make ECoChG more sensitive, Al-momani et al. (2009) measured the SP/AP ratio and compared it to the amplitude and duration of the SP and AP. Using this approach, as opposed to cut-off scores, they yielded more sensitive ECoChG results to MD. The sensitivity that was reported was much higher (92%) than previously estimated. The findings in this study used cut-off scores to obtain a diagnosis, which may have contributed to the disagreement with other diagnostic tools. The findings of this study demonstrated a higher consistency of ECoChG measures across frequencies, suggesting that the sensitivity of the ECoChG method may be improved with some modification of the rules for discrimination. Another explanation for the possibly poor sensitivity is the nature of the disease itself. As MD is a fluctuating disease, particularly in the early stages, if the test is administered when no symptoms are present, it is unlikely that a positive diagnosis will be made. In other words, repeated measures at different points

of time or administering instrumental test around the time when symptoms occur would be useful for enhancing the power of the diagnostic tool.

The AAO-HNS CHE criteria may be more sensitive, but not as specific as the objective measure due to the way the assessment categorises patient information and the subjective nature of the assessment. As van de Heyning et al. (1997) described, it does not take the length of vertigo attacks into account nor does it measure the severity or frequency of the tinnitus and aural pressure. It also does not take into account the severity of the hearing loss. Not all patients with MD present with all of the symptoms in the criteria. In turn this can lead to an incorrect diagnosis, making this method of diagnostic assessment restrictive.

The findings from this study showed that both ECoChG and AAO-HNS CHE criteria independently diagnosed a similar number of patients with MD. This is in contrast to the study by Stapleton and Mills (2008), where the AAO-HNS CHE criteria diagnosed three times more patients with MD when compared with Prosper Ménière's original description of the disease. However, Prosper Ménière's original description of the disease is not comparable to ECoChG.

The findings also showed that according to the AAO-HNS CHE criteria, the majority of patients had a hearing loss and many of them also had vertigo. Fewer patients presented with tinnitus and aural pressure. The severity of these symptoms is unknown, as none of the three diagnostic assessment tools evaluated in this study assessed for this. It was evident in the results that not all patients presented with all of the symptoms, which is part of the difficulty of diagnosing MD. However, there was a tendency for the "positive" group, regardless of the tool used for the classification, to exhibit a higher correlation between the severity score of the four key symptoms. This is expected as the discrimination of subjective assessment tools is based on the

weighing of the accumulating effect. However, the ECoChG diagnosis, which was based on the physiological measure instead of the reported symptoms, also yielded the same finding, suggesting that the physiological measures may be pertinent and sensitive to the changes underlying the fluctuating symptoms.

Audiometric measures comparing both ECoChG and the AAO-HNS CHE criteria showed similar results. A large proportion of total number of patients with diagnosed MD had a hearing loss and fewer had normal hearing. This was expected as typical MD symptoms include a hearing loss. However, there were a number of patients with diagnosed MD who had normal hearing. An explanation for this is that the progression of hearing loss has not occurred yet in this population of patients with normal hearing. As Sajjadi & Paparella (2008) has described, a sensorineural hearing loss in the affected ear may fluctuate over months and years in those with MD. Also, a large portion of the present sample who had a negative ECoChG diagnosis in combination with a “possible MD” or “probable MD” AAO-HNS CHE diagnosis had normal hearing. This demonstrates agreement between the two diagnostic tools and exhibits hearing loss as a common symptom of Ménière’s disease.

4.2 Evaluation of Electrocochleography

As the AAO-NHS-CHE criterion is a subjective diagnostic tool, the application of the criteria is susceptible to rating inconsistency. The physician needs to take great care when examining a patient using the subjective method, as it can narrow the focus of the assessment and create an inaccurate diagnosis, leading to false positives. The ECoChG measures allow for objective assessment, which has the advantage over subjective assessment in avoiding rating bias. However, this method of assessment captures only one aspect of the pathophysiological sign associated with MD and does not take into consideration the symptoms a patient has, such as vertigo,

tinnitus, or aural pressure. Most importantly, hearing loss can affect the recordings if a patient has severe-to-profound hearing loss and their cochlea does not respond to the acoustic stimulus presented to them. On the other hand, the finding that a higher correlation between the SP/AP ratios at adjacent frequencies (i.e., 0.5 and 1 kHz, 1 and 2 kHz, and 2 and 4 kHz) in the “positive” group suggested that the correlations between these ECoChG measures may discriminate the effect endolymphatic hydrops had on the auditory system from other effects. In other words, the physiological measures would be more sensitive if applied with a better discriminating rule, such as one that reflects the consistency of the measures between adjacent frequencies.

Another benefit of ECoChG is it takes unilateral and bilateral MD into diagnostic consideration, as each ear is assessed independently. This makes treatment for the patient more efficient. The AAO-NHS-CHE criterion does not assess whether the patient has unilateral or bilateral MD. This has serious considerations when treating a patient with symmetrical hearing loss.

The ECoChG is an invasive and more costly test than the AAO-HNS CHE. However, the ECoChG method provides objective assessment, may be more specific, and tests for bilateral MD. The drawback of ECoChG as a diagnostic tool is that if the patient has recovered from their symptoms at the time of testing (in the early onset of MD), the test will not diagnose them as having MD. Due to the time it takes for an appointment which includes a hearing test, it is not practical to assess a person at an initial consultation and there may be a long hospital waiting list for the test to be done. It is costly, time inefficient and impractical for the patient, physician, and audiologist to repeat this test until they are fully symptomatic of MD. This may take years after onset, and the patient may be in tremendous discomfort over this period if they are

waiting on a positive ECoChG result. It is therefore not good practice to use ECoChG as the only diagnostic evaluation tool for the assessment of MD.

ECoChG is better used as a complementary test in the diagnosis of MD with other tests, such as the AAO-HNS CHE criteria or Gibson's Score. However, these tests are not 100% in agreement with each other on the diagnoses of MD. Therefore, each case should be assessed very carefully, with all tests looked at and an overall view of the outcome agreed on by the physician, but not taken on one test alone. If there is doubt, more testing should be done, and other MD diagnostic assessments employed, such as MRI.

It was hypothesized that ECoChG would yield more defined results in the diagnosis of MD than the AAO-HNS CHE criteria. The rationale was that ECoChG is more defined as it objectively yields a positive or negative test result to confirm diagnosis while the AAO-HNS CHE criteria gives broader definition as to whether a person has MD or not. ECoChG does yield more defined results in the diagnosis of MD than that of the AAO-HNS CHE criteria. However, due to its flaws, it is better used in combination with other MD assessment tools rather than used alone in the diagnosis of MD.

Both clicks and tone burst stimuli can be used to elicit an ECoChG AER. Tone bursts have been shown to provide more accurate measurements than clicks (Gibson, 1991). A study by Ge and Shea (2002) demonstrated that tone bursts had the advantage of greater frequency selectivity, making them more accurate at showing the degree of hydrops at specific turns of the cochlea. Gibson (1993) showed that the 1 kHz tone burst was more reliable than the click for the diagnosis of MD. The findings of the data in this study demonstrated that tone-burst ECoChG diagnosed more positive ears than clicks. More tone-burst ECoChG diagnoses were made at 1 kHz

than the other frequencies tested of 500 Hz, 2 kHz and 4 kHz, making this data in agreement with previous research findings.

4.3 Findings of the Study in Relation to Previous Research

On examination of the data, several conclusions can be drawn. Analysis between Gibson's Score, ECoChG, and the AAO-HNS CHE criteria indicated variable results below the Gibson Scale cut-off score of 7. In particular, the findings showed disagreement of the diagnoses of MD in the patients for the scores of 2, 3 and 4 between Gibson's score, ECoChG, and the AAO-HNS CHE criteria. The result for the AAO-HNS CHE diagnosis of "probable MD" is not of concern due to small sample size. Due to the limited literature on diagnostic assessment of Gibson's score, no comparisons can be made, except that of the findings detailed above.

It has been reported that MD typically occurs unilaterally rather than bilaterally (Neely, 2008). This sample reflects this trend. However, the findings from the current study show a higher percentage of patients tested positive for bilateral MD using the ECoChG assessment method than the other two methods. In a study by Paparella and Griebe (1984), it was reported that bilateral MD occurred in one in three patients. Half of the patients who developed bilateral MD did so 5 years after the onset of the first ear, suggesting that bilateral MD is a natural progression for the disease in some people. This is an important consideration when treatment is being offered for the ear presenting with MD symptoms, as every attempt at conservation of the non-symptomatic ear should be made.

The ECoChG method and Gibson's score are the only two diagnostic tools out of the three discussed that will take bilateral MD into consideration when making a diagnosis. Therefore, the AAO-HNS CHE could not be assessed for its ability to diagnose bilateral MD. The ECoChG method identified a larger amount of patients

with bilateral MD than Gibson's score. It is noteworthy that the patient identified in Gibson's score was also identified in the electrocochleography evaluation for bilateral MD.

There were several symptomatic differences resulting from the data analysis. Almost all patients with a positive ECochG score exhibited hearing loss and vertigo and to a lesser extent, tinnitus and aural fullness. This indicates that hearing loss and vertigo are the main symptoms of Ménière's disease for this sample. Paparella (1991) reported that many patients experience auditory or vestibular symptoms for months or years before the onset of other symptoms. The findings of this study showed that symptoms occurred in both isolation and co-occur with other symptoms.

The results indicated that many of the patients with a large threshold difference between ears in this sample returned a positive electrocochleography result and a "definite MD" AAO-HNS CHE diagnosis. This may suggest that a 20 dB HL or greater difference between audiometric thresholds should be referred to an Otolaryngologist for evaluation of asymmetric hearing thresholds. In this sample asymmetric hearing loss in combination with vertigo were the dominant symptoms of MD.

Demographic data, such as gender and age of onset in populations of Ménière's disease are essential to compare with other populations. The literature does not indicate that Ménière's disease is more common in males (Paparella, 1991). However, the findings in this study indicate strongly that more males have Ménière's disease, with almost twice as many males testing positive to electrocochleography as female.

The common age for acquiring Ménière's disease is approximately 40-50 years of age (Paparella et al., 1991; Vrabec et al., 2007). This sample shows most of

the patients with “definite MD” are between the ages of 41 and 80, making this sample a much older population of those with MD.

4.4 Clinical Implications

Findings from the current study offer some clinical implications for the assessment of Ménière’s disease. The current study confirms that there is a slight disagreement in the diagnoses of patients with MD between the diagnostic assessments of ECoChG and the AAO-HNS CHE criteria; however they are generally in agreement. As a result, it suggests that ECoChG cannot be used alone in the diagnosis of MD.

ECoChG used in combination with another assessment tools for the diagnosis of MD, such as the AAO-HNS CHE criteria or Gibson’s score is beneficial. If agreement is shown, then it is likely that the patient has MD, if there is a disagreement, then the case needs to be looked at closely, and other assessment tools employed.

4.5 Limitations of the Study and Future Direction

There are a number of limitations to the generalisation of the present findings. Firstly, although the number of medical records reviewed in the study was high, a total review of the entire patient list assessed for Ménière’s disease at Christchurch Public Hospital, Christchurch, New Zealand since the commencement of ECoChG testing at that hospital may be more representative of clinical population seen in the Canterbury area. Future studies may incorporate the rest of the assessed population to understand MD trends in Canterbury, New Zealand. This may in turn be extended to other regions of the country to allow for further assessment of the disease.

In addition, future studies involving the analysis of progression of hearing loss in the patients who presented with normal hearing in this study and were diagnosed with MD would be of interest. This would chart the progression that the hearing loss takes over the years and possibly a change in diagnosis, yielding information regarding the duration of the development from some symptoms to complete MD symptoms in this population.

Due to the limited literature on diagnostic assessment of Gibson's score, research involving the outcomes of this score is needed in order to compare it with other diagnostic methods that are available.

Furthermore without a clinically accepted "gold standard" for the assessment of MD, it is challenging to make the diagnosis or assess the predictive power of a diagnostic tool. MRI imaging is developing in Christchurch and may lead to a more robust assessment of MD.

4.6 Conclusion

This study highlighted some important points related to the assessment of Ménière's disease using different approaches. Firstly, it can be concluded that the three diagnostic assessment tools of electrocochleography, the AAO-HNS CHE criteria and Gibson's score are generally in agreement regarding a patient's diagnosis of Ménière's disease. Secondly, ECochG is an effective diagnostic tool but it should not be used as the sole assessment tool for the diagnosis of MD as its effectiveness may be dependent on the patient having full symptoms of the disease at the time of testing.

It is important that professionals are aware of the disagreement between these three tests and the advantage of using ECochG, in combination with another assessment tools, for the diagnosis of MD. The finding of the consistency between

ECochG measures across frequencies needs further investigation. Development in the area of MRI may provide better parallel validation for the diagnostic tools and open up this area of research extensively.

References

- Al-momani, M. O., Ferraro, J. A., Gajewski, B. J., & Ator, G. (2009). Improved sensitivity of electrocochleography in the diagnosis of Meniere's disease. *International Journal of Audiology, 48*, 811-819.
- Arts, H. A., Kileny, P. R., & Telian, S. A. (1997). Diagnostic testing for endolymphatic hydrops. In P. C. Weber (Ed.). *The Otolaryngologic Clinics of North America* (pp. 987-1005). Maryland, USA: Elsevier Inc.
- Asai, H., & Mori, N. (1989). Change in the summing potential and action potential during the fluctuation of hearing in Ménière's Disease. *Scandinavian Audiology, 18*, 13-17.
- Baloh, R. W. (2001). Prosper Ménière and his disease. *Archives of Neurology, 58*, 1151-1156.
- Bhatnagar, S. C. (2002). *Neuroscience for the study of communicative disorders*. (2nd Ed.). Philadelphia, USA: Lippincott Williams & Wilkins.
- Burkard, R. F., & Secor, C. (2002). Overview of auditory evoked potentials. In J. Katz (Ed.), *Handbook of Clinical Audiology* (5th ed.). (pp. 233-248). Philadelphia, USA: Lippincott Williams & Wilkins.
- Bohlen, H. K. H., Arenberg, K., & Gibson, W. P. R. (1990). Diagnostic reliability of electrocochleography for hydrops – ear canal/tympanic membrane versus transtympanic electrode placement. *Surgery of the Inner Ear, 269-280*.
- Committee on Hearing and Equilibrium (1972). Ménière's disease: criteria for diagnosis and evaluation of therapy for reporting. *Transactions of the American Academy of Ophthalmology & Otolaryngology, 76*, 1462-1464.

- Committee on Hearing and Equilibrium (1985). Ménière's disease: criteria for diagnosis and evaluation of therapy for reporting. *AAO-HNS Bulletin*, 5, 6-7.
- Conlon, B. J., & Gibson, W. P. R. (2000). Electrocochleography in the Diagnosis of Ménière's Disease. *Acta Otolaryngologica*, 120, 480-483.
- Costa, S. S., Sousa, L. C., & Piza, M. R. (2002). Ménière's disease: overview, epidemiology, and natural history. *Otolaryngology Clinic of North America*, 35, 455-495.
- Ferraro, J. A. (2000). Electrocochleography. In R. J. Roeser, M. Valente, & H. Hosford-Dunn (Eds.), *Audiology Diagnosis* (pp.425-450). New York, USA: Thieme Medical Publishers.
- Ferraro, J. A., & Durrant, J. D. (2002). Electrocochleography. In J. Katz (Ed.), *Handbook of Clinical Audiology* (5th ed.). (pp. 249-273). Philadelphia, USA: Lippincott Williams & Wilkins.
- Flourens, P. (1824). *Recherches expérimentales sur les propriétés et les fonctions du système nerveux dans les animaux vertébrés*. Paris, France: Crevot.
- Ge, X., & Shea, J. (2002). Transtympanic Electrocochleography: A 10-Year Experience. *Otology & Neurotology*, 23, 799-805.
- Gibson, W. P. R. (1990). The 10-point score for the clinical diagnosis of Ménière's disease. *Surgery of the Inner Ear*, 109.
- Gibson, W. P. R. (1993). A comparison of clicks versus tone bursts in the diagnosis of endolymphatic hydrops. Submitted to 'Proceedings of 1st International Conference on ECochG, OAE and Intra-operative monitoring'. Ed. Hohmann, D. Kugler Publications.

- Gibson, W. P. R. (1994). Electrocochleography Norms. Submitted to 'Proceedings of 1st International Conference on ECochG, OAE and Intra-operative monitoring'. Ed. Hohmann, D. Kugler Publications.
- Gibson, W. P. R. (1996). The role of electrocochleography in the understanding the pathophysiology of Ménière's Disease. *Auris Nasus Larynx*, 23, 12-17.
- Gibson, W. P. R. (2009). A comparison of two methods of using transtympanic electrocochleography for the diagnosis of Ménière's disease: click summing potential/action potential ratio measurements and tone burst summing potential measurements. *Acta Otolaryngologica*, 129, 38-42.
- Gibson, W. P. R., Moffat, D. A., & Ramsden, R. T. (1977). Clinical Electrocochleography in the Diagnosis and Management of Menière's Disorder. *Audiology*, 16, 389-401.
- Hall, J. W. (2007). *New Handbook of Auditory Evoked Responses*. Boston, USA: Pearson Education.
- Hallpike, C. S., & Cairns, H. (1938). Observations on the Pathology of Ménière's Syndrome. *Proceedings of the Royal Society of Medicine*, 31, 1317-1336.
- Havia, M., Kentala, E., & Pyykkö, I. (2005). Prevalence of Ménière's Disease in General Population of Southern Finland. *Otolaryngology-Head and Neck Surgery*, 133, 762-768.
- Horner, K. (1991). Old theme and new reflections: Hearing impairment associated with endolymphatic hydrops. *Hearing Research*, 52, 147-156.
- Horner, K. (1993). Functional changes associated with experimentally induced endolymphatic hydrops. *Hearing Research*, 68, 1-18.
- Jasper, H. H. (1958). The ten twenty electrode system of the international federation. *Electroencephalography and Clinical Neurophysiology*, 10, 371-375.

- McNeill, C, Cohen, M. A., & Gibson, W. P. R. (2009). Changes in audiometric thresholds before, during and after attacks of vertigo associated with Ménière's syndrome. *Acta Otolaryngologica*, 129, 1651-2251.
- Members of the Committee on Hearing and Equilibrium (1995). Committee on Hearing and Equilibrium Guidelines for the Diagnosis and Evaluation of Therapy in Ménière's Disease. *Otolaryngology-Head and Neck Surgery*, 113, 181-185.
- Ménière, P. (1861). Maladies de l'oreille interne offrant les symptômes de la congestion cérébrale apoplectiforme. *Gazette Medicale de Paris*, 16, 88.
- Monsell, E. M. (2005). Outcomes research and the AAO-HNS Foundation. *Otolaryngology – Head and Neck Surgery*, 132, 169-170.
- Morrison, A. W. (1997). Prosper Ménière (1799-1862): A synopsis of his life and times. *Ear Nose & Throat Journal*, 76, 626-631.
- Nakashima, T., Naganawa, S., Pyykkö, I., Gibson, W. P. R., Sone, M., Nakata, S., & Teranishi, M. (2009). Grading of endolymphatic hydrops using magnetic resonance imaging. *Acta Otolaryngologica*, 129, 5-8.
- Nakashima, T., Naganawa, S., Sugiura, M., Teranishi, M., Sone, M., Hayashi, H., & Ishida, I. M. (2007). Visualization of endolymphatic hydrops in patients with Ménière's disease. *The Laryngoscope*, 11, 415-420.
- Neely, J. G. (2008). Medical and Surgical Treatment of Sensorineural Hearing Loss. In M. Valente, H. Hosford-Dunn, & R. J. Roeser (Eds.), *Audiology Treatment* (2nd ed.). (pp. 241-270). New York, USA: Thieme Medical Publishers.
- Paparella, M. M. (1991). Pathogenesis and pathophysiology of Ménière's Disease. *Acta Otolaryngologica*, 485, 26-35.

- Paparella, M. M., da Costa, S. S., Fox, R. & Yoo, T. H. (1991). Ménière's disease and other labyrinthine diseases. In Paparella, M. M, Shumrick, D. A., Gluckmann, J., & Meyerhoff, W. L. (Eds.), *Otolaryngology* (3rd ed.). Philadelphia, USA: WB Saunders.
- Paparella, M. M., & Griebe, M, S. (1984). Bilaterality of Meniere's diseases. *Acta Otolaryngologica*, 97, 233-237.
- Patuzzi, R. B. (1996). Cochlear micromechanics and macromechanics. In Dallos, P., Popper, A. N., Fay, R. R., & Popper, A. (Eds.), *The Cochlea* (pp.186-257). New York, USA: Springer-Verlag.
- Patuzzi, R. B. (2009). Cochlear mechanics. In L. R. Squire (Ed.), *Encyclopedia of Neuroscience* (pp. 1041-1049). Berlin: Elsevier.
- Patuzzi, R. B., Yates, G. K., & Johnstone, B. M. (1989a). The origin of the low-frequency microphonic in the first cochlear turn of the guinea-pig. *Hearing Research*, 39, 177-188.
- Patuzzi, R. B., Yates, G. K., & Johnstone, B. M. (1989b). Changes in cochlear microphonic and neural sensitivity produced by acoustic trauma. *Hearing Research*, 39, 189-202.
- Ries, D. T., Rickert, M., & Schlauch, R. S. (1999). The peaked audiometric configuration in Ménière's Disease: Disease related? *Journal of Speech, Language, and Hearing Research*, 42, 829-842.
- Roeser, R. J., Valente, M., & Hosford-Dunn, H. (2000). *Audiology Diagnosis*. New York, USA: Thieme Medical Publishers.
- Sajjadi, H., & Paparella, M. M. (2008). Ménière's disease. *The Lancet*, 372, 406-414.

- Stapleton, E., & Mills, R. (2008). Clinical diagnosis of Ménière's disease: how useful are the American Academy of Otolaryngology Head and Neck Surgery Committee on Hearing and Equilibrium guidelines? *The Journal of Laryngology & Otology*, *122*, 773-779.
- Thorp, M. A., & James, A. L. (2005). Prosper Ménière. *The Lancet*, *366*, 2137-2139.
- Thorp, M. A., Shehab, Z. P., Bance, M. L., & Rutka, J. A. (2003). The AAO-HNS Committee on Hearing and Equilibrium guidelines for the diagnosis and evaluation of therapy in Meniere's disease: Have they been applied in the published literature of the last decade? *Clinical Otolaryngology*, *28*, 173-176.
- Tucci, D. L., & Gray, L. (2000). Radiographic imaging in otologic disease. In R. J. Roeser, M. Valente, & H. Hosford-Dunn (Eds.), *Audiology Diagnosis*. (pp.109-120). New York, USA: Thieme Medical Publishers.
- Valente, M., Hosford-Dunn, H., & Roeser, R. J. (2008). *Audiology Treatment*. New York, USA: Thieme Medical Publishers.
- Van de Heyning, P. H., Wuyts, F. L., Claes, J., Koekelkoren, E., Van Laer, C., & Valcke, H. (1997). Definition, classification and reporting of Meniere's disease and its symptoms. *Acta Otolaryngologica (Suppl)*, *526*, 5-9.
- Vrabec, J. T., Simon, L. M., & Coker, N. J. (2007). Survey of Ménière's Disease in a subspecialty referral practice. *Otolaryngology-Head and Neck Surgery*, *13*, 213-217.
- Watanabe, Y., Mizukoshi, K., Shojaku, H., Watanabe, I., Hinoki, M., & Kitahara, M. (1995). Epidemiological and clinical characteristics of Ménière's disease in Japan. *Acta Otolaryngologica (Suppl)*, *519*, 206-210.
- Yost, W. A. (2007). *Fundamentals of hearing: An introduction*. London, UK: Elsevier.

Appendix 1

MRI Study by J. Hornibrook, M. Coates, G. Goh & P. Bird

Within the practice of J. Hornibrook, the following two cases were reviewed for Ménière's disease (MD) using electrocochleography (ECoChG) and the AAO-HNS CHE criteria (Members of the Committee on Hearing and Equilibrium, 1995). Due to limited spatial resolution of 1.5 Tesla scanners, MRI studies of the inner ear have not been possible. Newer scanners with a greater magnetic strength make imaging of the inner ear now possible. Using a 3 Tesla scanner, endolymphatic hydrops has been demonstrated (Nakashima et al., 2009).

Procedure

MRI scans were conducted on two patients. The MRI used a 3 Tesla Magnet (General Electric HDX). Twenty-four hours prior to the scan, Multihance gadolinium 1.6ml in 10 ml saline was infused into the right middle ear of both patients over a duration of 45 minutes.

Patients

Patient 1 was an 80 year old male with vertigo attacks, mild right ear hearing loss and no aural symptoms. He obtained a negative ECoChG result and a "possible MD" AAO HNS CHE criteria diagnosis for Ménière's disease, with an overall diagnosis concluding that his symptoms were not MD.

Patient 2 was a 46 year old male with a two year history of vertigo attacks, progressive hearing loss in the right ear, tinnitus and aural fullness. He obtained a

positive ECochG result and a “definite MD” AAO HNS CHE criteria diagnosis for Ménière’s disease, with an overall diagnosis concluding that his symptoms were MD.

Results

Patient 1: Normal inner ear, no endolymphatic hydrops

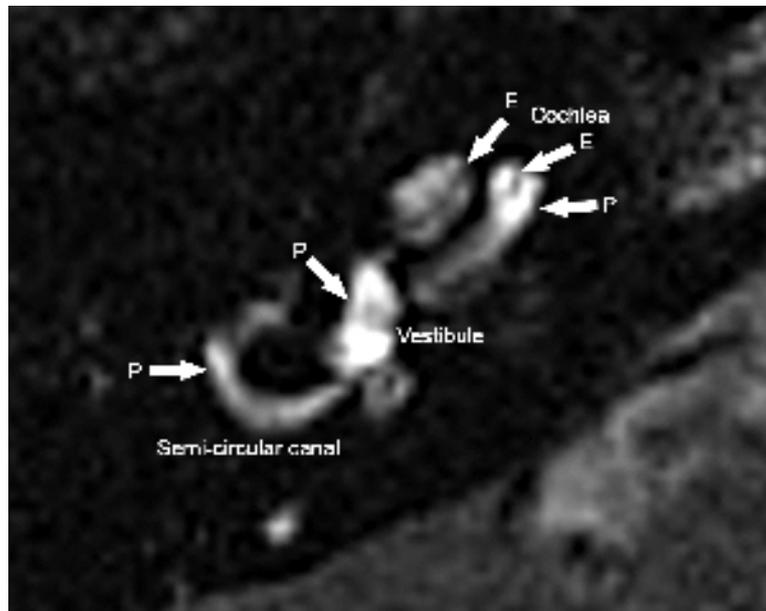


Figure 1. Perilymph sequence. The cochlea, vestibule and one semicircular canal are labelled. P= perilymph, E= endolymph. Brightly enhancing perilymph predominates in all areas. In the cochlea, a normal narrow endolymphatic compartment is seen. No hydrops.

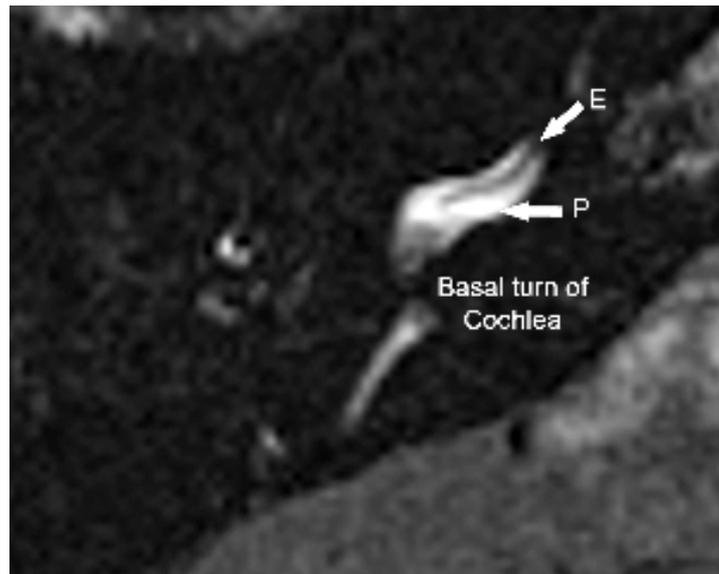


Figure 2. Endolymph sequence. The basal turn of the cochlea, with normal endolymphatic compartment. No hydrops.

Patient 2: Ménière's disease, endolymphatic hydrops present

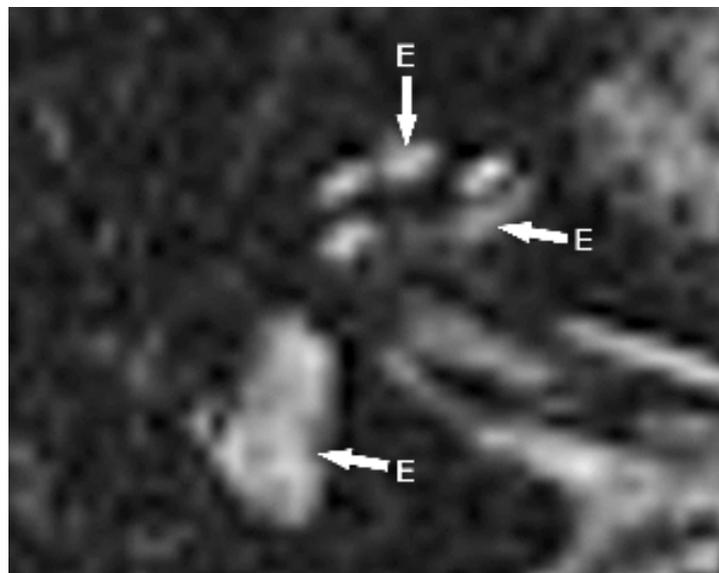


Figure 3. Perilymph sequence. A significant enlargement (33-50%) of the endolymphatic compartment in the cochlea. In the vestibule and semicircular canal endolymphatic hydrops (>50%) has displaced almost all perilymph.

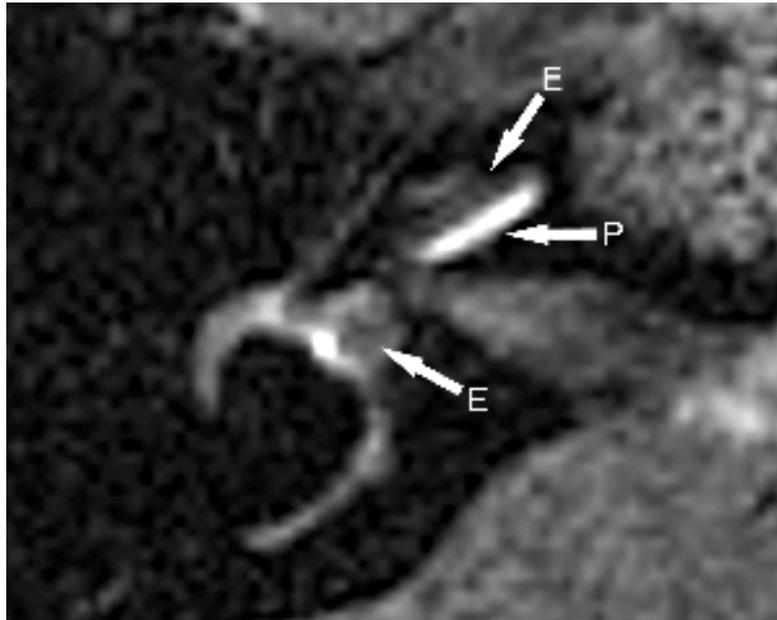


Figure 4. Endolymph sequence. An enlargement of the endolymphatic compartment in the cochlea. Endolymph fills the vestibule.

Concluding Remarks

These MRI images show a normal inner ear (Patient1) and an abnormal ear (Patient 2) resulting in endolymphatic hydrops, Ménière's disease. This result was in total agreement with the two pre-diagnostic assessment tools of ECochG and the AAO-HNS CHE criteria. With more research, this tool may have a new role in the diagnosis of MD and other inner ear conditions.

Appendix 2

Health Research Council approval letter

University of Canterbury Human Ethics Committee approval letter

4 March 2009

Catherine Kalin
Department of Communication Disorders
University of Canterbury
Private Bag 4800
Christchurch

Dear Catherine Kalin,

The evaluation of electrocochleography as a diagnostic tool for Meneire's Disease

Investigators: C Kalin, Dr E Lin (supervisor), Prof J Hornibrook, Dr G O'Beirne

Ethics ref: URA/09/06/EXP

The above study has been given ethical approval by one member and the Chairperson of the Upper South A Regional Ethics Committee.

Final Report

The study is approved until **4 March 2010**. A final report is required at the end of the study and a report form to assist with this is available at <http://www.newhealth.govt.nz/ethicscommittees>. If the study will not be completed as advised, please forward a report form and an application for extension of ethical approval one month before the above date.

Amendments

It is also a condition of approval that the Committee is advised if the study does not commence, or is altered in any way, including all documentation.

Please quote the above ethics committee reference number in all correspondence.

It should be noted that Ethics Committee approval does not imply any resource commitment or administrative facilitation by any healthcare provider within whose facility the research is to be carried out. The organisation may specify their own processes regarding notification or approval.

We wish you well with your study.

Yours sincerely

Alieke Dierckx

Upper South A Ethics Committee Administrator
Alieke_dierckx@moh.govt.nz

Ref: HEC 2009/LR/10

31 March 2009

Catherine Kalin
Department of Communication Disorders
UNIVERSITY OF CANTERBURY

Dear Catherine

Thank you for forwarding to the Human Ethics Committee a copy of the low risk application you have recently made for your research proposal “The evaluation of electrocochleography as a diagnostic tool for Ménière’s disease.”

I am pleased to advise that this application has been reviewed and I confirm support of the Department’s approval for this project, subject to final approval from the Health & Disability Ethics Committee. I will be pleased to receive a copy of their final approval when this has been granted.

With best wishes for your project.

Yours sincerely

Dr Michael Grimshaw
Chair, Human Ethics Committee

Appendix 3

The COV measures for patients retested at different points of time, showing the patient's gender and age and the ECoChG diagnosis on the day in the legend box (e.g., "F77: neg-neg" means the subject is a 77 year-old female who was diagnosed as "negative" on both visits with ECoChG measures.)

